UNCLASSIFIED

AD NUMBER
AD085593

CLASSIFICATION CHANGES

TO: **unclassified**

FROM: **confidential**

LIMITATION CHANGES

TO:

Approved for public release, distribution unlimited

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 01 NOV 1955. Other requests shall be referred to US Navy Chief of Naval Operations, Washington, DC 20350.

AUTHORITY

4 Oct 1965, USN memo; USNOL ltr, 29 Aug 1974

THIS PAGE IS UNCLASSIFIED

UNCLASSIFIED

AD. *85593*

DEFENSE DOCUMENTATION CENTER
FOR
SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION ALEXANDRIA. VIRGINIA

FOR ERRATA

AD 085593

OWING PAGES ARE CHANGES

TO BASIC DOCUMENT

Best
Available
Copy

U.S. NAVAL ORDNANCE LABORATORY

WHITE OAK

SILVER SPRING MARYLAND 20910

To all holders of   NAVORD Report 41?5

Title: Relative Accident Probability Analysis

4 October

Approved by Commander, U.S. NOL

(signature)

By direction

1

This publication is changed as follows:

Downgraded to UNCLASSIFIED as per memo NO:AMC:imw to HL via W,
N, and GA dated 4 October 1965

Today the principles of electric fuzing, represented by the
EX-200, are no longer considered classified.

085593

NAVORD REPORT 4135

FC

RELATIVE ACCIDENT PROBABILITY ANALYSIS

1 NOVEMBER 1955

U. S. NAVAL ORDNANCE LABORATORY

WHITE OAK, MARYLAND

FEB 29 1956

56AA   6424

RELATIVE ACCIDENT PROBABILITY ANALYSIS

Prepared by:

D. E. Allmand
J. H. Armstrong
R. H. Blair
E. W. Blevins
A. M. Corbin
M. B. Rowan

ABSTRACT: The complexity of modern ordnance makes difficult
the assessment of the overall effect on user safety of indi-
vidual design, manufacture, handling procedure or use factors.
An orderly process for the study of the relative safety of
alternate designs and/or practices is presented, with an
example of its use in analyzing a complex electro-mechanical
bomb fuze system.

This analysis process consists of:

1. Organizing accident-inducing happenstances into diagrams
indicating possible combinations resulting in accident.

2. Assigning best estimates of probability to the individual
happenstances and cross-checking for consistency.

3. Combining the resulting accident possibilities by appro-
priate mathematical processes.

4. Weighing the relative frequency of exposure to the vari-
ous hazard routes and the relative consequences of accident
at corresponding times and places in determining an overall
accident probability index.

5. Determining from study of these results the relative
safety of designs, effects of individual probabilities on
overall safety, points of especial hazard, areas for test,
etc. as a basis for administrative decisions.

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

CONFIDENTIAL 56AA   6424

The opinions stated herein are those of the Technical Evaluation Department and do not constitute a recommendation by the Laboratory for the use of this system of analysis. The process described has been found useful in the Department as an aid in reaching sound technical conclusions leading to administrative decisions and is presented in the interest of a more widespread appreciation for problems involved in achieving optimum ordnance designs.

It is recognized that the choice of method made herein is frequently arbitrary and that many alternative routes to similar results may exist. Further experience in the use of such analytical processes should lead to improvement through refinement and perhaps through some more basic changes in approach; comments on the methods and conclusions of this report are solicited.

The basic method reported was developed in the course of evaluation work on various fuzing and firing systems in the bomb, rocket, projectile and underwater ordnance programs. The analysis of the experimental bomb fuze given herein is to be considered exemplary only, since the particular design analyzed is not representative of a completed laboratory development. This report was prepared under tasks NOL-A2b-43-1, NOL-A2b-20-1 and NOL C7a-312-25.

JOHN T. HAYWARD
Captain, USN
Commander

R. E. Hightower
By direction

TABLE OF CONTENTS

ILLUSTRATIONS

CHAPTER 1

INTRODUCTION

1.1 The American concept of the importance of the individual
and the desirability of reliance on advanced weapons as a
substitute for mass manpower in creating a strong defense
would lead inevitably to emphasis on safety to the user in
ordnance design and utilization for humanitarian reasons alone.
Up to a certain point there is also a strong economic factor
in favor of safety; this is particularly true in the Navy
because of the potential loss of a major ship from almost any
ordnance accident. A morale factor must also be recognized,
since weapons must actually be used (both in practice exercises
and service) to be effective and those with poor reputations
safety-wise will be consistently slighted.

1.2 Conversely, providing safety in ordnance design tends to
increase weapon complexity, development lead time, and cost
(and thus to reduce availability) and to reduce reliability and
effectiveness. Offense being part of an effective defense, an
overly-safe weapon could contribute to unsafety of a fleet unit
by failing to intercept an attacker or by being so complex as
to be unavailable at the time and place needed. Balance between
safety, performance, availability and cost is therefore of the
utmost importance.

1.3 Striking the many balances (such as the right time to give
up concealment by starting an attack) involved in the playing
of the percentages which essentially makes up military tactics
is complex and difficult enough as it is without burdening the
fleet forces with explosive ordnance safety problems. Time
for training is limited and must not be wasted either in having
to learn complicated safety routines to make up for hazardous
ordnance or, on the other hand, in studying the extra readying
operations occasioned by excessive complexity added in the
interests of safety.

1.4 Everyone is for safety and against sin, but the exact
point of balance in safety of explosive ordnance is a point of
much discussion. The ordnance designer does not have the entire
matter in his hands, since many of the conditions of fleet use
are determined, re-examined and altered by others in the naval
establishment who are primarily concerned with tactics,
logistics, ship and aircraft design, etc. These people cannot
be familiar with all the detailed design considerations,

manner-of-use assumptions and closeted skeletons implicit in a piece of ordnance hardware. The ordnance designer does have the following responsibilities, however, which he should not seek to avoid:

a. _Good Design_. A safe design is not necessarily more complex or unreliable than an unsafe one. There will always be room for ingenuity and careful analysis in devising and selecting effective safing systems which do not disproportionately complicate or degrade the performance of ordnance.

b. _Balanced Design_. Each feature of a design added for safety's sake should be weighed carefully to see that it pays its way in increasing safety to an extent that makes up for any added cost, complexity, handling care and unreliability it introduces. Reducing one hazard is in vain if it contributes to increasing others disproportionately.

c. _Determination of Potential Hazards_. If safety in a design is less than desired, it can often be compensated for by handling and use practices. There is an obligation to explore possible avenues of unsafety to insure that no serious faults exist unknown and to make information available on which a decision as to the urgency and value of an improvement in design for safety can be based.

Approaches to Safety

1.5 This report is primarily concerned with fuzing system safety. In some cases, such as in projectiles, this may involve considering only a "fuze" itself; in other cases, as in Naval mines, many separate components, both in the expendable ordnance and the planting craft, form the ordnance safing and firing system and must be studied.

1.6 Over the long history of ordnance, safety has been sought by various approaches, and an extensive philosophy has been developed which assists an experienced ordnance engineer to arrive at a safe design without too many false starts. Some of the philosophies which have evolved may be summarized as follows: (many of the finer points which are essential to their real usefulness have, of necessity, been omitted here, and this should not be considered an all-inclusive list).

a. _The Interrupted Explosive Train_. This design feature has achieved virtually the status of a philosophy. By stopping the propagation of an accidental initiation at a safe point, it eliminates many of the problems otherwise associated with the

necessarily great electrical and/or mechanical sensitivity of
the primary explosive element which initiates the weapon. The
location of the interruption in the train, methods for eval-
uation, etc. are well established. The interrupted train
almost invariably complicates a design; if well designed, it
does not affect the reliability of the armed explosive train
but the mechanical operation of arming is an added phase of
operation which can rarely be 100% reliable.

b. The Fail-Safe Principle (in which failure of any part
to operate is made to lead toward a dud rather than unsafe
operation) is invaluable in avoiding accidents from unforeseen
possibilities of mal-treatment, misassembly and abnormal
environment. Its effect on reliability is direct and obvious.

c. The Series of Safety Features principle is based on
the sound assumption that it is easier to achieve perfection
by designing so that two or more independent safety features
(of a readily-demonstrated level of reliability) must all fail
for there to be an accident than by relying on a single feature,
which must be of undemonstrably high reliability and which will
fail if omitted or circumvented. The affect of these added
features on complexity and reliability is unfortunate and the
matter of actual independence must be most carefully examined.

d. The Overtest Philosophy seeks to demonstrate safety
by exaggerating the expected service environment to the point
where failures of parts may occur or where it is highly
unlikely that an equivalent shock, voltage or whatever will
ever be seen in practice. If failures induced are not of an
unsafe nature, they are disregarded. This pragmatic philosophy
weeds out many questionable features, but may be criticized as
leading to overdesign.

e. The Critical Defect classification* wisely requires a
higher degree of inspection and perfection in those attributes
of an individual piece of ordnance which affect safety. When
a great many parts are considered to affect safety (as in those
items relying on a series of safety features), however, there
may be so many critical features as to dilute available
inspection effort to the extent that the high quality level is
not actually assured. High rejection rates where many dimen-
sions are critical may jeopardize production and lead to
waivers being granted, again defeating the system. It is often

* Used in the Ordnance Classification of Defects, a Navy
document governing the inspection and acceptance of ordnance
material.

difficult to classify attributes; a dimension slightly out of
tolerance may affect operability only but become significant
safety-wise if farther out.

f. **Arbitrary Design-Feature Requirements** usually result
from long experience and undoubtedly have kept a great deal of
bad ordnance out of service. Such things as cocked firing
springs, etc. may be banned because of their contribution to
unsafety in particular cases; applied in other cases, such bans
may not really apply and may seriously handicap design.
Perhaps the most serious problem is that it is human to assume
that if all bans and requirements are complied with, safety is
assured. This is not true because of the impossibility of
including in any list all ramifications affecting future
designs.

1.7 The various philosophies furnish much assistance, but
there are simply too many considerations, some of them at times
conflicting, to be assessed continuously for their overall
effect. There is also the possibility that so many safety
features will be in series that the net addition to safety of
some of them is insufficient to justify their cost (using cost
in the inclusive sense) while other accident sources which are
not considered because they do not happen to be covered by the
philosophies are of much greater importance.

1.8 It is the purpose of this report to discuss the methods
and possibilities of a more all-inclusive method of analysis
which attempts, without pre-judgement as to the importance or
unimportance of individual probabilities, to put the pieces
together into an overall, semiquantitative picture in which the
total effect of individual design or usage features can then be
assessed more readily. No new or additional test methods or
design features are assumed or involved, but a more penetrating
(and laborious) method of analysis is proposed. This analysis
cannot eliminate the need for design ingenuity or the con-
ducting of test programs. As will be discussed, however, it
appears that demonstrably valid conclusions useful in design
and evaluation can often be reached by the logical combination
of existing data and reasonable estimates.

1.9 While some of the thought processes involved in accident
probability analysis are similar to those in reliability
analysis, the practical handling of the problem is almost
completely different. One fundamental reason for this is that
there are at least only a few ways in which a system can
function as intended, while there are almost numberless ways in
which it can be unsafe. The philosophical approach is looking

toward a complete safety analysis must therefore be basically
different from chat seeking the closest estimate of the percent-
age reliability of a weapon, and the mathematics used will be
correspondingly different. Wherever concepts related to those
in reliability or effectiveness analyses are used here, a
similar terminology and symbology has been sought, but in most
of this analysis the selection of terms and symbols is
arbitrary.

CHAPTER 2

THE RAP ANALYSIS

2.1 In essence, the Relative Accident Probability Analysis is
an orderly plan for breaking the complex problem of overall
safety of an ordnance item into component parts which can be
assessed by logical treatment. The first major breakdown
separates factors of situation, exposure, and severity. Of
these three, the situation is by far the most complex.

The Situation

2.2 A "Situation" is defined as a period in the life of the
ordnance during which the environment and conditions which
affect safety and the results of a premature actuation are
essentially constant. This means that accident likelihood and
consequences are essentially of one averageable value. To
illustrate this, consider a fuze stored with and without
booster. Here the environment is essentially the same but the
results of premature actuation would be quite different. Two
situations would result. On the other hand, a fuze which is
undergoing setback is under very different environmental con-
ditions from one sitting on the shelf. Here the situations are
more obviously different. In brief, two factors are influ-
ential in the definition of situation. The first deals with
the likelihood of a premature actuation which depends to a great
extent on the environment and the arming status of the item.
The second deals with the probable results of an actuation and
is more of a convenient and necessary artifice which will be
better appreciated when the severity factor is discussed.

2.3 In the RAP Analysis the entire life history of the
ordnance or ordnance component is reviewed and the situations
which are likely to arise are listed. This encourages a syste-
matic consideration of the factors in a situation which influ-
ence the safety of the ordnance. In broad categories, the
history starts with manufacture and assembly. This is followed
by transportation and storage and delivery to fleet units for
tactical use. Handling and stowage on units of the fleet usual-
ly differ from handling ashore. In many cases, components are
assembled to make complete weapons, thus changing the picture
as far as lethality and damage potentiality are concerned.
Delivery to the target involves the conditions of launching and
arming. Some ordnance which was prepared for use will not be
fired and will be returned to the magazine, ship, or base.

Although these broad situations cover the normal expected life, there are other situations which need to be considered. These are situations which are not intended or desirable, but which cannot always be avoided. Some examples are fire, airplane crashes, hung ordnance, etc. The situations, both normal and unusual, which need to be considered all depend on the type of ordnance and conditions of its use.

Probability Factor

2.4 Before becoming too involved in the situation, it is advisable to see how the situation fits into an overall probability of accident. For each situation, a number is obtained which is the best estimate of the probability of an accident in that situation. This number is the probability factor (P). For the purposes of this presentation of the RAP analysis, an accident is defined as the explosion of the booster or larger charge. This restrictive definition is used only because the danger of explosion is usually the primary concern in considering overall safety. The RAP analysis can be used or extended to compare other bad effects (such as the opening of the parachute on a mine while still attached to the planting aircraft) by simply redefining the accident. The probability factor is obtained from a situation diagram, a procedure which will be explained in detail in later paragraphs. A distorted picture of the overall safety of the device would be obtained if the probability factors of all situations were given equal weight. There are two reasons for this. First, there are some situations which are common to all devices and some which occur in the life history of only a few. Adjustments must be made for the relative frequencies with which the ordnance is exposed to the various situations. Second, the effects of premature actuation are far more serious in some situations than in others. A device which is more susceptible to actuation in a situation where the consequences are more grave must be penalized in its comparison with other devices. A factor which might appear to affect the weight to be given a probability factor is situation duration. Some situations extend for a long period of time while others exist only a moment. However, it has been found that this factor is best handled directly in the situation probabilities. The most important reason for this is that the situations impose the environments which may differ so much in severity and character that time duration as a separate factor may be meaningless and distorting.

Exposure Factor

2.5 To adjust for the frequency of exposure to situations, the probability factor (P) obtained from a situation is multiplied by an exposure factor (E). The exposure factor is dimensionless. It is determined by the average number of times to which the average piece of ordnance will be exposed to the particular situation. For a situation such as initial assembly, its value is unity; for a situation such as "crash aboard carrier with hung ordnance" it will be much smaller, while in some situations such as "fuzing missile" involving frequently disassembled ordnance, it may be greater than unity. The exposure factor is subject to change by changes in tactical doctrine, field handling procedures, etc. (e.g., by a change from a doctrine of carrying a weapon on anti-submarine patrol to one in which weapons are used only on strike missions) more often than by changes in design, and therefore may well be retained as a separate figure until the final stage of an analysis, to facilitate trying out tactical or handling procedure changes for their affect on safety.

Severity Factor

2.6 Adjustment for the consequences of an accident in a situation is made by multiplying the probability factor (P) and exposure factor (E) by a severity factor (S). The severity factor is to represent the average "cost" of an accident of the assumed type occurring in the situation considered. "Cost" may be an inclusive term including not only the direct loss in damage to material, ships and installations and in casualties to personnel, but also perhaps some estimate of the loss of tactical capabilities and advantage, compromise of secrecy, effect on morale, etc. The degree of inclusion of these intangibles must be stated. It is often satisfactory to make the severity factor a relative term rather than an absolute one (as by considering S for the explosion of a fuze booster while the fuze is being handled separately as unity, S for an accident involving probable loss of a bomber as 10^5, and S for an accident jeopardizing a carrier as 10^6, for example). This is because competitive designs being analyzed will be used with a similar main weapon charge, involving the identical hazard if accidently exploded in similar situations. The S factor is to represent only the cost associated with malfunction of the ordnance being analyzed; it would be an estimate of the difference in cost between that of an aircraft accident in which a bomb aboard exploded and one in which it did not. In situations where the damage varies with the exact time of the accident (as in the case of a rocket premature which damage

CONFIDENTIAL
NAVORD REPORT 4135

range of the launching aircraft) a weighted average value is worked out, subject to later closer individual analysis if results warrant.

2.7 The severity factor is essential in weighing the relative safety of ordnance designs and should not be left out except in making comparisons limited to one specific weapon and situation. The figure of not more than one accident "in a million" often quoted as a goal for navy fuzing does not adequately express the true need for all types of ordnance. If acceptable in the planting of submarine-laid mines, it is clearly excessively stringent on a relative basis for aircraft-laid mines, and likewise if acceptable for a fuze alone is inadequate for the same fuze in a 2000 lb. bomb on a carrier deck.

Relative Accident Probability Index

2.8 The product PES is a number which characterizes the hazard from the device in a situation and is properly weighted for comparison with other situations. Since P is expressed as the probability of an accident in a situation per device, S is dimensionless, and S is expressed as the monetary loss por accident (in some multiple of dollars), the product PES is the probable relative dollar loss through accidents in a situation per device - an index which rates the hazard from the device in a situation. To obtain an overall picture, the indexes of all situations are added. The result is a number ($\sum$PES) called the Relative Accident Probability index (RAPI) which can be used to compare different devices. It has been found most meaningful to express the overall accident cost attributable to the use of a design of ordnance in terms of cost per unit of ordnance manufactured or assembled. Such figures are then in form to be compared with the cost of manufacture of the ordnance unit, with the cost of use (logistics, firing, planting, etc.) and with the tactical usefulness per unit (e.g. shipping damage per mine).

2.9 An additional factor may be recognized: the probable number of units to be used. Since this can always be cranked in at the end of the process without ordinarily modifying the figures that have gone before, we have arbitrarily chosen to exclude it from the RAP analysis. If added, this factor has the interesting property of tending to reduce the effect of the severity factor, the bigger-bang items of ordnance for other reasons normally being used in smaller quantities. The total cost of accidents from all the ordnance of a given type manufactured tends to be more constant.

9
CONFIDENTIAL

Factor Determination

2.10 Of tne factors discussed normally only the situation probability factor (P) is complicated to understand and difficult to base on known values. The general procedure for establishing this factor will be considered briefly here; since probability factor determination is the nub (and the biggest part by far) of the RAP analysis, the detailed procedure is discussed in the later chapters on Situation Diagrams, Probability Assignment and Summation of Path Probabilities. At this point, a glance at Fig. 4-3, a diagram of the paths to unsafety in one situation for a bomb fuze, may help clarify the discussion to follow.

2.11 The analysis procedure to determine the probability of an accident in a given situation is akin to the development of a complicated wiring diagram from component circuits. The whole diagram is far too complicated for normal thought processes, but the individual components and circuits are quite simple.

2.12 In the RAP situation probability analysis, the individual circuit equivalent is the "accident path". An accident proceeds from some "event" or happenstance through what ever other events are required by the design of the ordnance item and the circumstances at the time to the explosion of the booster and/or main charge. In most cases other happenstances are required to complete the path. The events are not necessarily in time sequence; a previous event such as omission of a safety device in manufacture may become part of an accident path later when some other untoward event starts the accident process.

2.13 In a situation we must consider a multiplicity of accident paths, for there are almost always several ways in which safety may be defeated. The only meaningful overall probability of accident for a given situation is the summation of all these individual paths. In practice, the analysis process approaches this figure by a systematic listing of all foreseen paths, their arrangement in a diagram, and their combining by appropriate mathematical processes.

2.14 The equivalent of the individual component in the wiring diagram is the "event", a single happening or condition whose probability under the conditions peculiar to the situation can be estimated from experience or a priori knowledge or determined by test. Examples are the accidental dropping of a fuze in such a manner as to close an inertia switch, the shorting

of two wires in the process of assembling a fuze, the ignition
of a pyrotechnic delay column by heat from an adjacent explosive
motor, or the inappropriate turning of a safety switch in an
aircraft ordnance firing circuit control box.

2.15 The keystone of the Relative Accident Probability
Analysis is the use of the same value for the same event in
different designs or systems being considered in each case where
the same conditions exist. For example, in comparing two mortar
fuze designs externally and operationally similar, the possi-
bility of a second round's being dropped into the mortar while
the previous one is still within the barrel would be assumed the
same for each. Since most competing systems include many
common design features and the same external factors are oper-
ating on both, it is often possible to get an appraisal of
their relative safety that is more accurate than the knowledge
of the probabilities of individual events used in making the
analysis, due to this canceling effect.

2.16 When the whole summation has been made, the results can be
reviewed to see the parts significantly responsible for the
total. The product of the probabilities of the individual
events making up each path is the probability of an accident
via that path. If this path probability is small, the effect
on the overall safety of the probability value of each event
which occurs only in such low-probability paths is also small,
no matter how high the individual event probability may be.
Conversely, if an individual event occurs in a short accident
path having a relatively higher probability, its value has
great effect on the answer. These relationships make the
analysis very effective in pin-pointing design features where
improvement in safety can best be sought, in selecting areas
in which determination of probabilities by test is important
and warranted, and in determining the maximum change in overall
safety that would result from eliminating a safety feature or
from reducing the probability of some event tending toward
accident to zero.

Purposes of the RAP Analysis

2.17 Presently foreseen uses of the RAP analysis are given in
the following paragraphs. Specific ways in which a particular
example of a RAP analysis could be used as a basis for tech-
nical and administrative decisions are given in Chapter 9.

Uses of the Relative Accident Probability Analysis:

a. To afford a logical procedure for considering all
the routes to unsafety by an orderly consideration of the

things that can go wrong throughout the life history of a fuzing system, thus avoiding "bloopers."

It can hardly be assured that all paths will be found, but the probability of missing a serious path is cut down by any systematic consideration. This is particularly important where divided responsibilities are involved (BuOrd-BuAer; Army launcher and Navy fuze; etc.) and there is a serious likelihood that both parties may miss checking a possibility for accident in the belief that the other is aware of it and taking precautions.

b. To channel design and evaluation effort (safety-wise) into fruitful channels by affording a fairly quick index, a' priori, of the net benefit possible from removing a hazard-contributing possibility, establishing a risk more closely by test, etc.

There can be little gain in overall safety from eliminating or studying a hazard which is not causing accidents, and the effort involved, often major, may represent inefficient use of money and engineering. Furthermore, side effects of the change may result in a worse overall situation. For example, express highway construction might result in increased total hazard if blowouts, rather than collisions and other factors which superior highway engineering could reduce, were the principal cause of accidents.

c. To foster simplified ordnance design by permitting the use of novel types of safing or the elimination of some existing design requirements if the alternative systems can be shown to afford equal or better overall safety.

The ultimate criterion of a safe design is that it not cause accident expense, not that it pass certain tests or contain certain features. The closer the actual use of this criterion can be attained, the better will be the balance between safety, operability, and manufacturing and development cost. It is our belief that money and talent spent on overall estimating methods and their application will yield a greater return at this time than similar effort in ordnance design, test, or specific test-method development programs. This is true only because of the

generally good safety which is characteristic of
American ordnance at present and the extreme complexity
in ordnance design which is rampant despite earnest
individual efforts to fight it.

d. To furnish guidance in the determination of handling
and tactical doctrine for existing designs of ordnance as it is
affected by safety considerations.

Operations are often spoken of as involving a
"calculated risk," usually without real calculations.
The RAP Analysis furnishes a framework for such risk
studies and therefore more realistic guidance.

Things the RAP Analysis Won't Do

2.18 RAP Analysis Will Not:

a. Estimate within a close range the accident cost and
rate for an ordnance design.

The individual probabilities going into the picture
are not well enough established in most cases to be
put on an accurate quantitative scale, and the summa-
tion cannot be closer than the average of its parts.
This is why the term "Relative" is included in the
title; because of common terms appearing in the
analysis of different competitive designs and in
different situations in the same design, many valuable
comparisons can be made, and most administrative
decisions can be made correctly on such a basis, but
the answer cannot be expected to be a $\pm 10\%$ matter
unless it happens that only a few individual proba-
bilities are significant in the answer and that these
are ones on which extensive data are available.

CHAPTER 3

SITUATIONS IN THE LIFE HISTORY OF A BOMB FUZE

3.1 The first step in the RAP analysis of a piece of ordnance is the division of its complete life history (from a specified initial point to a specified end point) into analytically discrete situations. The reasons for such division are discussed in general terms in paragraphs 2.2 and 2.3; to initiate the exposition of the RAP analysis technique by specific example, this chapter introduces a bomb fuze chosen as the ordnance item to be considered and gives the reasoning behind the division of its life history into situations preparatory to the analysis covered in detail in succeeding chapters.

The Bomb Fuze EX-200

3.2 In selecting a fuze to be used as an example, several fuzes were considered. The EX-200 was chosen because it incorporated electric arming, which is a relatively new method for fuze arming, along with the usual mechanical interruption and interlocks. The choice of this fuze was further influenced by the fact that the development stage was nearing completion and it was felt that an analysis of the fuze would be profitable in regard to the forthcoming evaluation. As it happened, development of this fuze was subsequently cancelled. However, the EX-200 turned out to be a good choice for illustrating the method because its complexity required consideration of a wide variety of factors in numerous combinations, thus giving experience in many problems in such an analysis.

3.3 The EX-200 is an impact fuze for an athwartship well designed to detonate the GP low drag bombs. The fuze was designed for interchangeable use in bombs having the new 2.781 inch fuze well. It contains an interrupted explosive train with a positive lock on the "out-of-line" rotor when in the unarmed position. The fuze is energized electrically and the arming and firing pyrotechnic delays, which are electrically fired, are selected by means of control gear in the aircraft at the time of bomb release.

The bombardier may select two firing delay times (instantaneous and 50 ms) and two different arming delay times (6.5 ± 0.5 and 10 ± 0.5 seconds) depending upon the tactics of the mission. This is accomplished by two dual position selector switches in the charging gear (SW_1 and SW_2 of Fig. 3-2 .

The fuze comprises three separate firing trains, each leading to a common 96 gram tetryl booster. Each train consists of a primer, detonator and tetryl lead. The primers are seated in a stypol housing and extend down into the aluminum die-cast rotor and lead housing. The detonators are housed in a steel rotor. All electrical components are encased in the potted stypol housing. Also included in the aluminum die-cast housing are two explosive actuators. Both operate switches and, in addition, one turns the rotor into the armed position.

3.4 Figure 3-1 is a schematic diagram of the electricl circuit of the fuze. The circuit diagram shows the switches in the normal non-operated position. Arming and firing times of the fuze are determined by the choice of the magnitude of the applied voltage and its polarity. If a charging potential of 300 volts is chosen with a polarity such that the grounded side of the fuze circuit is positive, the fuze will have a nominal arming time of 6.5 seconds and will fire instantaneously upon impact. The circuit action is as follows: The applied voltage charges the two storage capacitors C_1 and C_3 and fires the actuator A_1 which, after a nominal delay of 2 seconds, operates switch S_1. The 225 volt diode then breaks down, charges the condenser C_4, and in the process fires the actuator A_2. After 4-1/2 seconds, the actuator aligns the rotor and operates the switch S_2. On impact the switch R-SW-1 closes and fires both the instantaneous and 50 ms primers. The primers will fire in time order. If the opposite polarity is chosen, the IN48 diode will prevent current flow through the instantaneous primer, allowing only the 50 ms primer to fire. Thus the choice of a charging potential of 300 volts provides an arming time of 6.5 seconds (2 seconds from the instantaneous actuator A_1 delay time and 4-1/2 seconds from the arming actuator A_2 delay time) and the choice of the polarity determines if the firing on impact is instantaneous or is delayed 50 milliseconds.

3.5 If a 10 second arming delay is desired with instantaneous firing upon impact, a 195 volt charging potential is chosen with a polarity such that the grounded terminal of the fuze is positive. The condensers C_1 and C_3 and the actuator A_1 operate as described above. However, in this case the 225 volt diode will not function since the applied voltage is less than its breakdown potential. Instead the storage condenser C_1 discharges through the CRC circuit composed of itself, R_1 and C_2. These components are so chosen that there will be a 3-1/2 second delay before condenser C_2 charges to a sufficient potential to break down one of the low voltage (110) diodes. When the diode fires, the 4-1/2 second delay actuator (A_2) is

activated and the fuze arms approximately 4-1/2 seconds later.
Firing of the instantaneous and 50 ms primers occurs upon
impact as described above. If 10 second arming with 50 ms
firing delay is desired, the polarity of the 195 volt charging
potential is reversed. The circuit action is identical as
before with the exception that the opposite low voltage diode
passes current and fires the 4-1/2 second actuator. The two
diodes are connected in parallel with reversed polarities to
provide for the two polarities of the charging potential. Only
the 50 ms primer fires as described above.

3.6 The condenser C_3 which is also charged along with the
condenser C_1 during the charging of the fuze is connected
through an impact switch designated R-SW-2 in Figure 3-1 to a
shorting switch and an eleven second delay primer in parallel.
The shorting switch operates by the action of the two second
actuator A_1. It provides for sterilization of the fuze in the
event a premature impact sufficient to operate the "jiggle"
switch occurs within two seconds after the fuze is charged. If
an impact occurs after two seconds and before the selected
arming time of 6 or 10 seconds, the arming actuator A_2 and the
switches it controls will not have operated. Hence the instan-
taneous and 50 ms primer will not be fired. However, the 11
second primer will be initiated; the fuze meantime will have
completed its arming cycle.

3.7 Also shown in Fig. 3-1 is the rotor lock shaft and the
drop switch S_3. The drop switch within the fuze is restrained
by a shear disc until the instant of drop. The extended shaft
of the drop switch locks into a hole in the rotor. In the
event of premature action by the arming actuator A_2 or the
primer and detonators, the rotor would be held in the unarmed
position. When the drop switch has acted, by the pulling away
of the charging insert and plug, its extended shaft is withdrawn
from the rotor; however, the rotor is still held in the safe
position by a shear wire. After about two inches of free fall,
the drawing out of the charging cable causes switching to be
completed in the bomb rack which allows the charging voltage to
be applied to the fuze. Voltage is applied until the disc is
sheared and the charging insert is pulled away from the fuze.
This occurs after about 6 inches of free fall. The release of
the shaft also operates switch S_2 which disconnects the internal
circuit of the fuze from the external contacts. The switches
designated in Fig. 3-1 as R-SW-1 and R-SW-2 close the circuits
from the condensers to the primers upon impact. They are en-
cased in the stypol housing and are omnidirectionally sensitive,
and they operate on 30 g or greater impacts.

3.8 The charging gear located in the plane is shown schematically in Fig. 3-2. At any time up to the instant of drop the pilot or bombardier may select the arming and firing delays desired. These delays are established by the selection of the positions of switches SW_1 and SW_2 respectively. The only other switch remaining for the bombardier to operate is the bomb release switch or, if need be, the bomb jettison switch.

3.9 The combination of electrical arming and charging is a relatively new and untried system for United States bomb fuzing. The forces associated with free falling bombs which are normally used as a means of arming do not readily lend themselves to fuzing systems for low drag bombs since the requirements prohibit the use of arming wires and air vanes. Because of these design restrictions, it becomes necessary to depend upon the aircraft charging system for part of the safety which cannot be designed into the fuze. This is accomplished in the EX-200 fuzing system by installing, in series with the firing lead, switches and interlocking relays which prevent the energizing current from getting to the fuze input terminals until the desired time. Some of these switches are shown in Fig. 3-2. SW_5 is a "pull-out operated and shorting switch." While in the normal position, this switch maintains a short across the fuze input terminals and interrupts the firing circuit. This switch is operated by the falling bomb as it drops free of the rack. The series connected shackle interlock switches designated SW_3 and SW_4 break the firing circuit as long as the shackles are in closed position. These switches close as the shackles open to release the bomb. The interlock relay designated RB_1 also isolates the firing circuit from the plane supply voltage. This relay is activated by the bomb release switch. An additional switch not shown in the schematic was proposed for use in the landing gear to interrupt the charging circuit when the landing gear was down. This was to provide additional safety during fuzing, take off and landing. The final switch is the master armament switch which controls all the armament power and must be closed before dropping. Thus a minimum of 6 switches is used to add to the safety of the fuzing system.

3.10 After the bomb is in place in the rack, the fuze is pushed up into the well from below, and the retaining plug is screwed in and tightened. The charging plug from the bomb rack can then be inserted into the fuze at any time before take off.

3.11 Prior to drop, the bombardier has selected the arming and firing delay desired by choosing the proper settings of the charging gear. From this point on, the actual drop is the same as for any normal bomb release. At the instant of drop, the

bomb release switch is pressed; this operates the interlock
relay (R). The charging voltage then appears at the switches
in the bomb rack. At the same time the bomb release solenoid
is activated; the shackles begin to open and when opened, close
the shackle interlock switches. After about two inches of free
fall, the "pull-out operated shorting and charging switch" SW₅
causes switching to be completed in the bomb rack, unshorting
the fuze input and applying voltage to the fuze until the disk
is sheared and the charging insert is pulled away from the bomb.
Arming then proceeds as described in the paragraphs above.

Division of Life History into Situations

3.12 The life history of a fuze such as the EX-200 is made up
of several periods which have been defined in paragraphs 2.2 and
2.3 as situations. In order to make these divisions, it is
necessary to study the environments in which a fuze finds
itself, the state of assembly and arming of the fuze and the
severity of any accident which might occur in these environ-
ments. Backtracking a little, it appears that the life history
of fuzes falls into two more basic periods of its existence,
which are in turn divisible into situations. The fuze's life
begins after its manufacture; then there follows a period of
what might be considered a latent existence during which the
fuzes are handled in large groups or lots. It performs no
functions and has very little influence on other ordnance.
Transportation usually takes place in sealed containers or
ammunition carriers from the loading plant to a place of storage,
where it is kept for an indefinite period of time. During this
so-called quiescent period, the environment of the fuze, while
varying from time to time with handling, transportation, ambient
temperature, etc., is within averageable limits for the purpose
of setting up a situation. Another consideration is the result
of a premature actuation. As will be seen later, the results
of a premature action in this early period of a fuze's exist-
ence will be quite different and considerably less severe than
in any other period of its life.

3.13 After a period of time, the fuze will be removed from
storage, transported to a new locality, unpacked and made ready
for the use for which it was manufactured. It is at this point
that the remainder of a fuze's life cycle passes comparatively
fast as compared to its storage existence. Here the fuze finds
itself in several different environments which may change rather
abruptly and on which the prospect of premature actuation may
greatly depend. In addition, since the fuze is now associated
with larger quantities of explosive and is in the proximity of
vulnerable equipment of war such as planes and ships, the
severity of a premature actuation is increased considerably as

compared to that of its first period of existence. Thus it seems that two basic factors determine the beginning and end points of a situation. They are (a) the environment and state of arming which influence the events which may cause premature actuation, and (b) the results of a premature actuation.

3.14 The first situation then in the life history of this fuze entails all of this first basic period of existence and is called storage, handling and transportation outside of ordnance. In case it did become initiated, the explosion would probably be confined to the ammunition carrier and there would be insignificant damage to the storage area. In essence, this situation is made up of the events that may occur from the time of assembly through storage and transportation to the point of unpacking just prior to the fuzing of the bombs. This division is adequate for this fuze. Other fuzes requiring preparation (such as applying arming wires) may warrant division into additional situations.

3.15 After a fuze is unpacked and made ready for use, it is here that its second period of life begins. After the protection of its container is removed, it is inserted into the fuze well of the bomb. This situation, known as fuzing, exists for only a short period of time. It begins with the insertion of the fuze into the well and ends with the closing of the container cover. The fuze is now in a different environment as compared to that of transportation and storage. The likelihood of being dropped or spuriously initiated increases as it is handled during removal from the container and inserted in the bomb. The severity of an accident may be increased by the fact that the fuze and bomb are brought together physically. Similar to fuzing, there is the reverse situation of defuzing. This situation exists because there may be reasons for removal of the fuze from the bomb, as would be the case if tactical plans had changed and bombs cannot be stored in a fuzed condition. It is likely that the defuzing situation would be more hazardous than fuzing, since electrical connections may have been made and the plane may have been in flight and subjected to the environment associated with normal flight. It is

considered that the time required for defuzing and the severity in case of an accident would be the same as for fuzing.*

3.16 After the bomb is fuzed, there may be occasions that will necessitate the handling of a fuzed bomb. This might occur if the bomb has to be removed from one plane to another. This operation, or situation, is designated as fuzed bomb handling and includes all events following the act of fuzing to the actual connecting to a plane. During the situation, the fuzed bomb may be transported in a bomb carrier from one part of the deck to another, passing in the proximity of other bombs or planes. There exists the possibility of collision with objects on the deck, or the bomb falling from the carrying vehicle. In this particular instance, it has been pointed out in paragraph 3.12 that the normal procedure would not involve the handling of a bomb fuzed by the EX-260. However, it is anticipated that operating conditions could cause deviations from this normal procedure often enough to require its inclusion in the analysis.

3.17 After the bomb is fuzed, the electrical connections between the fuze and plane have to be made. Here there is a marked change in the environment of the fuze because it is now under the influence of the electrical system of the plane. A path to its internal circuitry has been established and the probability values assigned to the events of the situation are affected. The connecting of a fuzed bomb to the airplane thus becomes a situation. The act of making physical connection such as the engaging of the bomb lugs must be considered in the situation, although normally this would be done before the bomb is fuzed.

3.18 After the fuzed bomb is connected to the plane, there will be last minute checks of switches and electrical connections. During the check out period there exists a possibility of certain critical switches being pushed and even the chances of accidentally dropping the bomb from the rack onto the deck. Although the severity of an accident during this check out period is probably no higher than when the fuze is being connected to the plane, its environment has changed to the

* The mechanical factors involved in fuzing and defuzing are often opposite in direction (as in the case of a fuze that is screwed into a projectile) and may therefore be profoundly different in effect, particularly if logical (though perhaps unauthorized) methods are used which apply loads in unintended locations. In mechanical fuzes particularly these factors must be very carefully considered.

extant that the fuze is now more than ever under the influence
of the electrical system of the plane so that this checking out
period on deck before take-off is necessarily a separate
situation.

3.19 The next situation in which a fuze finds itself is take-
off. This is a short period of time beginning at the time the
plane has been given the signal to take-off until it is air-
borne and out of danger of an accident which might affect the
carrier. There has been a change in the fuze's environment in
that it is now exposed to launching accelerations and plane
vibrations which might possibly defeat some of its mechanical
features. As the landing gear is retracted, an additional
safety block from the plane's electrical power system is re-
moved, thus increasing the probability of extraneous charging
currents getting into the fuze. The severity of an accident in
this situation is reduced somewhat by the fact that the danger
to the carrier and to other planes on the carrier is decreasing
as the situation progresses. Closely associated with the take-
off situation is the period of normal flight. The severity of
an accident is greatly reduced since the carrier is no longer
in any danger; however, the environment is much the same as
that of take off. In these two situations the electrical
system of the plane and the charging gear are the predomi-
nating factors in the environment of the fuze and they increase
the probability of spuriously initiating the explosive
components. The situation of flight includes the events from
normal take off to intentional drop or return to base without
trying to drop.

3.20 The next logical situation in the life history of a fuze
is normal drop. This could very well be the last situation in
a fuze's life for it is here that it performs the work for
which it was intended, and at the end of the situation is
destroyed. This situation includes the events which might occur
from the time the bomb is released until it is safely separated
from the plane. Here the safety features of the plane are no
longer in effect, current has been applied to the fuze
initiating some of the explosive components within a lethal
range of the plane, and also at the instant of drop the
positive mechanical interlock is removed. The probability of
the bomb being safely separated from the plane before the
occurrence of an accident depends now on a small number of
series events since many of the safety features have been
deliberately removed in this new environment. Jettison is a
special case of normal drop; since the fuze has not been armed,
the hazard should be less. Therefore, no special situation is
called for unless there is some peculiarity of the process
necessary for jettisoning which might change the story.

3.21 Although the life of a fuze should have ended after normal drop, there are occasions when it is desirable to return aboard the aircraft carrier without dropping the ordnance.* For this reason, it is necessary to consider the events which might occur on the return. It is evident that both normal and abnormal situations can exist when a plane returns with its bombs, and these conditions create different environments for the fuze which necessitate the defining of separate situations. The first consideration will be a <u>return</u> with <u>normal</u> <u>landing</u>. This situation is made up of the events which might occur during the landing. The events will be similar to those during the take-off situation. Preparations were made to drop the bomb, but it was not dropped. In this situation, it is assured that the ordnance and plane are in a normal condition during the landing.

3.22 Several types of abnormal situations can develop during the return and landing with bombs. The environment of these situations makes it necessary to establish separate situations. A situation can possibly arise when an attempt was made to drop the bomb, but the drop was unsuccessful, resulting in the situation of <u>return and landing with hung ordnance</u>. The bomb release and jettison switches have been closed and possibly the fuze charging switches. Some malfunction prevented a normal drop but the extent of this is not known. In this situation it is assumed that the ordnance comes off on the landing. The events of the situation are influenced by the acts of closing the switches during flight and the mechanical impacts of the bomb as it rolls or slides down the deck.

3.23 Other situations will come into the picture when a crash landing of the plane occurs. One situation under such an environment would be that of <u>crash on landing with hung ordnance</u>.** Here it is assumed that the bomb is dislodged and the charging plug may be detached from the fuze. There is a slight chance that the fuze is charged. Another situation

* Since it would always be <u>desirable</u> to bring the ordnance back aboard as contrasted to jettisoning the bomb or ditching the aircraft, this situation should be considered in any analysis in the hope of showing that bringing it back is also safe. If the hope is not borne out, restrictions can then be placed in the use doctrine.

** With small bombs it may be necessary to consider a bomb hung by one lug. This situation, which was not considered in this analysis, could be considerably more dangerous since the charging plug may have pulled out normally when the drop was attempted.

which presents itself would be crash on landing with normal
ordnance. This involves the events which could occur during
what started out to be a normal landing but resulted in a crash
of the plane.

3.24 Keeping in view the events that happen after a crash on
landing, two final situations are described. If a bomb is not
detonated during a crash landing, disposal operations must
follow. The bomb may be defused or it might be disposed of by
letting it slide overboard without defuzing. Thus the rend-
ering ordnance safe or disposal of ordnance after crash landing
is a situation made up of events which are pertinent to this
operation. It does not include defuzing by the normal method
discussed in paragraph 3.17.

3.25 The final situation to be considered is that of removing
the bomb from the plane. It may or may not necessarily be
influenced by the crash environment, but includes the removing
of a fuzed bomb from the plane for any reason. It is not a
normal procedure to remove a fuzed bomb from a plane so it is
most likely to be an operation caused by a crash landing and
influenced by that environment. The removing of a fuzed bomb
from a plane is discouraged in bombs using the EX-200 fuze, by
the fact that the fuze is easily removed. The removal of a
fuzed bomb is most likely to take place in a situation where it
is physically impossible to defuze the bomb, such as in a
crash landing.

3.26 Table 3.1 lists the situations into which the life
history of the EX-200 has been divided for the initial RAP
Analysis. It is usually necessary to further define in writing
the end points of the individual situations in making up a list
for use as a working reference in an actual analysis; this has
not been included here because of the uncertain status of the
EX-200 design which makes it difficult and unprofitable to
pin down certain assembly and use procedures which had not been
firmly established.

TABLE 3.1

Situations

a. Storage, Handling and Transportation Outside of Ordnance

b. Fuzing

c. Defuzing

d. Fuzed Bomb Handling

e. Connecting Fuzed Bomb to Airplane

f. On Deck Before Take Off

g. Take Off

h. Flight

i. Normal Drop

j. Return with Normal Landing

k. Return and Landing with Hung Ordnance

l. Crash on Landing with Hung Ordnance

m. Crash on Landing with Normal Ordnance

n. Rendering Ordnance Safe or Disposal of Ordnance after Crash Landing

o. Removing Bomb
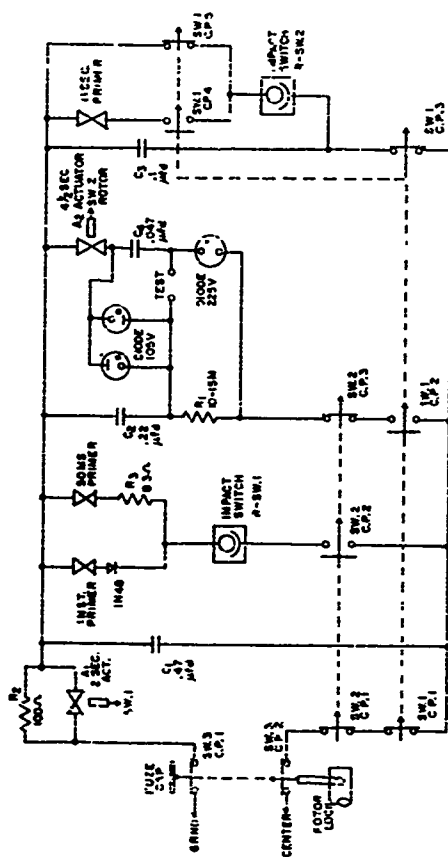
FIG. 3-1 EX-200 SCHEMATIC DIAGRAM
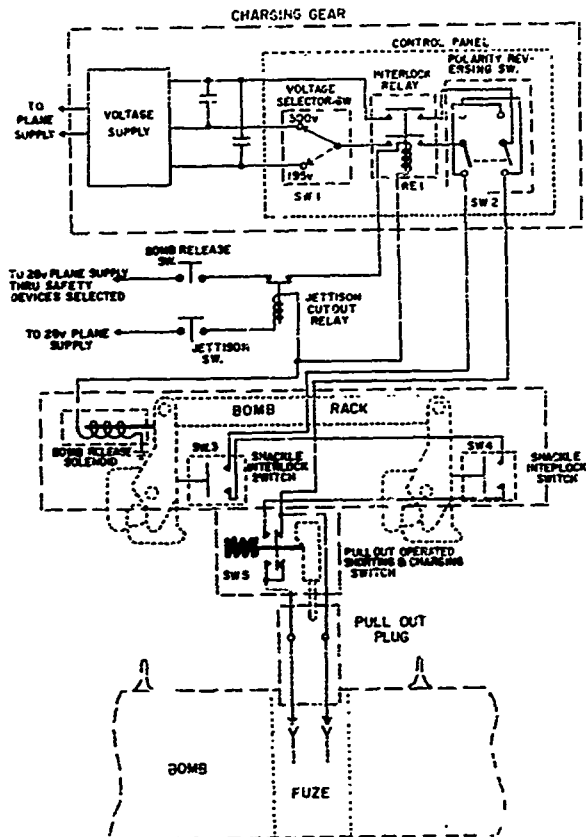
FIG.3-2 SCHEMATIC DIAGRAM OF CHARGING CIRCUIT

CHAPTER 4

SITUATION DIAGRAMS

4.1 Situation diagrams are full of events having probabilities. There may be a probability that the detonator is supersensitive; a probability that a rotor was not installed; a probability that shocks have broken a pin; etc. Some of these events will be in series; i.e. safety is not defeated unless all the events occur. Others will be in parallel; i.e. either event circumvents safety. Situation diagrams involve a lot of manipulation of the probabilities of these events and in this respect there are certain rules which apply.

Series - Parallel Events

4.2 If an event (P_1) has a probability of success (p_1) and another event (P_2) has a probability of success (p_2) and the two events are independent, then the probability that on any one try both events will be successful in the product p_1p_2. If the success of the operation depends on the concurrent success of these two events, the events are in series. In this case, the probability of success of the operation is given by $p = p_1p_2$. But if the success of the operation depends on the success of either or both of the events, the events are in parallel. The probability of success of the operation is then given by: $p = 1 - q_1q_2$ where q_1 and q_2 are the probabilities of failure of the events. Since $q_1 = 1 - p_1$ and $q_2 = 1 - p_2$, the expression in terms of successes is:

$$p = p_1 + p_2 - p_1p_2$$

4.3 As a very simple example of series events, assume that the successful operation of a fuze depends on the firing of the primer and arming of the rotor. If p_1 is the probability that the primer will fire and p_2 is the probability that the rotor will be in the armed position, then the probability that the fuze will operate is p_1p_2. If we assume a very bad explosive train with $p_1 = 0.7$ and $p_2 = 0.7$, the probability that the train will operate is 0.49.

4.4 Redundancy in explosive trains can be used to illustrate parallel events. Assume that a fuze contains two identical primers, either one of which can actuate the explosives, and that these primers each have a 0.7 probability of operating. The probability that one or both of the primers will operate is $0.7 + 0.7 - 0.49 = 0.91$.

Diagrams of Events

4.5 The examples given have been very simple. In situations the events can become quite complex and combinations of series and parallel events exist. Graphic representations are used to show the relations and sequences of events in the situation. These are called situation diagrams. The very simple diagrams of two events in series and two in parallel are given by:

series
$P = P_1 P_2$

parallel
$p = p_1 + p_2 - p_1 p_2$
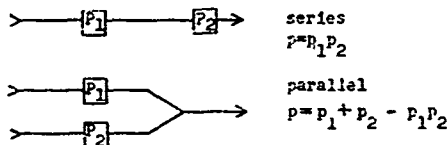
In the above diagrams, the event P_1 has the probability of occurrence p_1 and the event P_2 has the probability of occurrence p_2. The events are independent; i.e. the occurrence of P_1 does not change p_2 etc. An example of a series-parallel combination of events is given by:
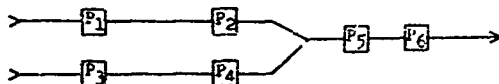
An expression for the probability of success where the events are mutually independent is obtained by breaking this into parts. Since P_1 and P_2 are in series as are also P_3 and P_4, and P_5 and P_6, we can set down a new diagram:
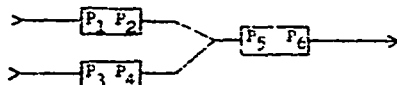
By this notation P_1P_2 is an event formed by combining the events P_1 and P_2 and it has a probability of success $p_1 \, p_2$. Now P_1P_2 and P_3P_4 are in parallel and the probability of success through these paths is:

$$p_1p_2 + p_3p_4 - p_1p_2p_3p_4$$

However, this is in series with P_5P_6, so the total expression becomes:

$$(p_1p_2 + p_3p_4 - p_1p_2p_3p_4) \quad p_5 \, p_6$$

and expanding:

$$p = p_1p_2p_5p_6 + p_3p_4p_5p_6 - p_1p_2p_3p_4p_5p_6$$

A more detailed discussion of the manipulation of these probabilities is given in Appendix A .

Cross Products

4.6 It was noted that the expression for the probability of success when two or more events are parallel contains cross products. If P_1 and P_2 are parallel. p is given by:

$$p_1 + p_2 - p_1 \, p_2$$

Here p_1p_2 is a cross product. If P_1, P_2, and P_3 are parallel, then

$$p = p_1 + p_2 + p_3 - p_1p_2 - p_1p_3 - p_2p_3 + p_1p_2p_3$$

Here p_1p_2, p_1p_3, p_2p_3 and $p_1p_2p_3$ are all cross products. The significance of the cross products may best be explained by using the simple example of two parallel events in which the success of either event means the success of the operation. The expression for this is:

$$p = p_1 + p_2 - p_1p_2$$

The probabilities p_1 and p_2 are associated with events P_1 and P_2. Since success depends on the occurrence of P_1 or P_2 or both, the situation is represented graphically by Fig. 4.1.

For this example, we can imagine that the areas bounding P_1 and P_2 are scaled to the probabilities p_1 and p_2; i.e. $p_1 > p_2 > p_1 p_2$. The total area encompassing P_1 and P_2 is the probability of success. However, it will be noted that the area obtained by adding p_1 and p_2 is too large by the amount $p_1 p_2$. The cross product $p_1 p_2$ appearing in the expression $p = p_1 + p_2 - p_1 p_2$ is therefore a correction for the simultaneous occurrence of P_1 and P_2 which is one success and not two. It is also interesting to note that when events must occur simultaneously (or in series), the only useful area is that bounding $p_1 p_2$. Fig. 4-1 helps to illustrate why the probability of success tends to decrease when the number of series events increases.

4.7 The probability of success involving three events where success depends on the occurrence of any or any combination of the events is given by:

$$p = p_1 + p_2 + p_3 - p_1 p_2 - p_1 p_3 - p_2 p_3 + p_1 p_2 p_3.$$

The "plus sign" associated with $p_1 p_2 p_3$ is not immediately obvious, but is easily explained by Fig. 4-2. The sum $p_1 + p_2 + p_3$ includes the area $p_1 p_2 p_3$ three times. The three corrective terms $p_1 p_2$, $p_1 p_3$, and $p_2 p_3$ each contain $p_1 p_2 p_3$, and since they are subtracted, they effectively remove the area $p_1 p_2 p_3$. But since the simultaneous occurrence of the events P_1, P_2 and P_3 is a success, the probability $p_1 p_2 p_3$ must be included and it is therefore added. The cross product terms of four or more parallel events can be analyzed in a similar manner.

4.8 In the complicated series - parallel arrangements of events which characterize a situation diagram the cross product terms become very difficult to handle. Their importance is evident when the probabilities involved are fairly large, as in the example given in paragraph 4.4. But the MAP Analysis concerns safety failures and accident probability and therefore deals with probabilities which are relatively small. For example, the omission of a rotor, arming caused by shocks, primer ignition by static electricity, etc. are events which occur relatively infrequently. Probabilities of 0.1 would be large for such events. Values of 0.01 or 0.001 would more nearly represent the expected range. When the primary values are so

small the cross products become exceedingly small. If two
parallel events have equal probabilities of occurring of 10^{-2},
for practical purposes it is just as meaningful to speak of the
combined probability as 2 in 100 rather than 100 in 10,000.
In most cases in the RAP Analysis, the cross products can be
dropped. If this were not true, the analysis as presented here
would become too involved to be practical."

4.9 No definite rule can be given regarding the dropping of
cross product terms. In general it is desirable to neglect
them entirely since this makes the analysis much simpler.
when this is done, the final answer will be correct if it is
rounded off before the cross products have an effect. In those
cases where it is desirable to carry figures in the answer which
are of the same magnitude as cross product terms, there is no
alternative but to include the significant cross products. This
problem will be discussed further in Chapter 6.

Symbols

4.10 Since the diagrams may contain a large number of events,
nomenclature can become a problem. In games or experiments
where the outcome is classed either as a success or a failure,
it has been customary to associate "p" with the probability of
success and "q" with the probability of failure. The RAP
Analysis is concerned with safety failures, and for consistency
it might seem reasonable to use the letter "Q" with appro-
priate subscripts to identify all events and "q" with appro-
priate subscripts to identify all probabilities. However, it
has been found that in complicated situations the subscripts
become unwieldy and offer little clue to the nature of the
event represented. The use of a series of letters has proved
more satisfactory.

4.11 In a situation the probability of a safety failure of a
device is determined by:

    a. Influences of environment
    b. Characteristics of auxiliary mechanisms and gear
    c. The characteristics of the device itself

    * The accident paths in different situations are also in
parallel with each other. Neglect of cross products between
situations is justifiable, however, because if the number of
accidents in any one situation is large enough to produce a
significant cross product with the accident probabilities in
another situation, the design is so unsafe that it will have to
be revised, thus making a very close RAP Luc value of only
academic interest.

In general the environment exerts forces on the device or on the auxiliary gear which tend to defeat safety, and the response of the device and auxiliary gear depend upon their characteristics. By this reasoning, there is a logical breakdown which can be used to advantage in establishing nomenclature. Then, by definition:

K with appropriate subscript will denote the existence of a dangerous mechanical influence (such as shock, crushing, etc.)

E with appropriate subscript will denote the existence of a dangerous electrical influence (such as static electricity, RF fields, power lines, etc.)

G with appropriate subscript will denote the existence of a miscellaneous dangerous influence (such as fire, chemical, etc.)

4.12 Within the device or auxiliary gear a safety failure will depend on the fault, failure, or omission or some component and/or the proper or near-proper functioning of other components. Therefore by definition:

P with appropriate subscript will denote the proper or near-proper functioning of a component in the device.

Q with appropriate subscript will denote the failure, fault or omission of a component in the device.

R with appropriate subscript will denote the proper or near-proper functioning of a component in the auxiliary gear.

S with appropriate subscript will denote the fault, failure or omission of a component in the auxiliary gear.

One additional factor which will need consideration is timing. It will frequently happen that certain events will lead to a accident only if they occur in a particular order at a particular time. This frequently decreases the chance of an accident. Then by definition:

T with appropriate subscript will denote the occurrence of a necessary order or other timing of events.

In the sense intended here timing will of necessity become an
event. It is not intended that this timing should be used to
adjust varying durations of situations (such as 10 years
storage as opposed to 10 seconds falling). As mentioned in
paragraph 2.4 the duration of situations is considered when
probabilities are assigned to the events and is not a simple
multiplication factor since the environment and forces involved
are so different in different situations. The timing which will
appear in diagrams as the event T will be concerned with the
order of events or with a restriction on time in which the
event must occur. For example, if an accident can occur if
event A is followed by event B, but not if event B is
followed by event A, then the only accident path is A
followed by B. This order is in itself an event. By intro-
ducing this event, T, the importance of the order is recog-
nized, and later in the analysis when probability values are
being assigned to A and B these need not be complicated by the
necessary order of events. As a second example, if event A
must occur during some normal function of the device (such as
during the burning time of a pyrotechnic column) the restric-
tion on the time during which event A will contribute to an
accident will reduce the probability of an accident by this
means. Again during the assignment of probabilities it will
frequently be much easier to assign a probability of
occurrence to event A without considering the effects of the
time restriction. The timing is then a separate series event.
This process of simplifying events is discussed further in
paragraph 4.15.

4.13 To the events K will be assigned probabilities of occur-
rence m; to the events E will be assigned probabilities of
occurrence e; etc. Upper case letters represent events and
lower case letters represent the probabilities of the
occurrence of these events. To illustrate this, the path
P_2O_4 representing two series events will have a probability

P_2O_4.

4.14 The nomenclature outlined above provides the advantage
that in the diagram it is possible to tell at a glance if the
event occurs outside the ordnance system or, if within,
whether it is in the device itself or in the auxiliary gear.
The symbols are much easier to remember because the subscripts
do not become so unwieldly and the letters immediately
associate themselves with types of events.

Preparing a Stituation Diagram

4.15 The complexity of a diagram depends to a great extent on the complexity of the device being analyzed and the desires of the analyst in reducing events to simple form. The analyst plays an important part for he must balance the inclusiveness of his event, which if too inclusive makes probability assignment very difficult, against the complexity of his diagram. For example, if the analyst defines E_1 as the event that in the situation shock will break a detent which, if properly aligned, will fall free permitting the firing pin to strike the primer which fires and causes flame to impinge on the lead because the rotor is absent, he is well on his way toward arriving at a very simple diagram. But his troubles will arise when he tries to assign a probability m_1. If, on the other hand, he defines E_1 as the event that shock will break the detent, P_1 as the event that the detent is in a particular orientation, q_1 as the event that the rotor will be missing, and P_2 as the event that the primer will initiate the lead, he is going to have a more complex diagram but will stand a good chance of having figures on which to base his estimates of the probabilities. In general, it is preferable to simplify the individual events at the expense of complicating the diagram.

4.16 It is felt that the steps involved in preparing a diagram are best portrayed by the use of an example. In Chapter 3 the electric Bomb Fuze EX-200 was described. One of the situations listed was "normal drop" (situation "S"). A diagram for this situation appears as Fig. 4-3. This diagram will be developed step by step to show the thought involved.

4.17 To reconstruct the situation briefly, we are concerned with a bomb fuzed by the Electric Bomb Fuze EX-200 which is in the act of being dropped on a target. Although it is true that the bomb may drop from an internal rack through bomb bay doors or may drop from an external rack, those are considered sufficiently similar to be included in a single situation. The act of releasing the bomb removes all safety provided in the release gear; i.e. the switches which prevent charges from getting into the fuze are purposely closed. A charge is put on the condensers in the fuze and the arming cycle is automatically set in motion. From the instant of release until safe separation of bomb and plane is realized, the plane is in danger of being destroyed or damaged if a premature explosion should occur.

4.18 From the instant of release, the time to complete arming depends upon pyrotechnic and C delays in the fuze and how these might have been affected by previous environments. The fuze becomes progressively more dangerous or more likely and capable of being initiated as a function of time. On the other hand, the airplane is less likely to be destroyed or damaged as the distance between bomb and plane increases. This distance is a function of time. It is necessary to strike an average somewhere in the time or space when the plane is in danger. This is done by the choice of severity factor, i.e. the cost of the accident is taken as some fraction of the value of the airplane.

4.19 In the interval during which the bomb is within lethal range, what could go wrong? What events could cause a premature bomb burst? The answers to these questions will be found in the accident paths. The accident paths will combine to form a diagram and from the diagram a relative accident probability or probability factor can be obtained.

4.20 In the description of the operation of the fuze it was noted that: (a) charging is accomplished through the bridge wire of a 2 second actuator thus initiating it, (b) the 2 second actuator operates several switches, one of which supplies energy to the 4-1/2 second actuator, and (c) the 4-1/2 second actuator turns the rotor, thus completing the arming of the fuze. On the average, 6-1/2 seconds is considered to be sufficient time for the bomb to fall to a safe distance, and therefore situation "1" is defined as existing for 6-1/2 seconds from the instant of bomb release. In the physical description it was pointed out that the primers and actuators are located in a plastic section which also houses the electronic components. The rotor is in a casting which fits below the plastic section. Let us assume that in operating, the 2 second actuator develops too much pressure and ruptures the copper bellows and that the hot gases thus released initiate a nearby primer. This event we will call P_2. Let us further

assume that the 4-1/2 second actuator was initiated spuriously at some earlier time and was able to effect rotor arming because the rotor lock shaft was short or missing. These events will be called O_4 and q_{12}. The three events in series will mean an accident. Schematically, this accident path looks like this:

$$\rightarrow \quad \boxed{P_2} \quad \boxed{q_{12}} \quad \boxed{O_4} \quad \rightarrow$$
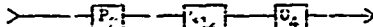
4.21 At first glance this accident path appears to be far-fetched. There is good likelihood that it is, but this is something that will come out when probability values are assigned to the events and compared to other paths. In setting down accident paths for a situation diagram, it is always necessary to repress the urge to label the path as inconsequential or absurd and therefore not worth considering. But with the further consideration that a safety failure rate of not more than one in one million is a goal in fuze design, it becomes evident that an accident may be in itself very improbable. If this goal is to be realistic, a lot of individual paths containing a lot of crazy combinations of events will have to be considered seriously. Therefore the path which is a "most unfortunate" combination of "highly improbable" events must not be ignored; added to many more like it, it contributes its bit to an accident probability of real proportions.

4.22 Our first event P_2, resulted in the firing of a primer. With the primer firing, there are ways besides the previous actuation of the 4-1/2 second actuator in which the fuze safety could be defeated. If the rotor had never been installed (event q_9), the primer would fire directly at a lead. The firing of the lead by the primer we will call F_{10}. The two paths combined look like this:
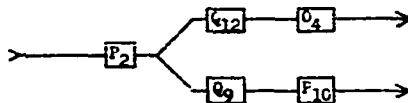
Obviously there are other ways in which the safety supplied by the rotor could be defeated. The primer could fire the lead directly even with the rotor in the unarmed position (q_8), or the primer could fire the detonator in the unarmed rotor (P_5) and this could fire the lead (F_9). It is possible that rough treatment and handling could have broken the shear wire permitting the rotor to turn to the armed position (N_4) or that the shear wire was never present and the rotor worked itself into the armed position (q_7). Combining all of these gives the following portion of the final diagram:
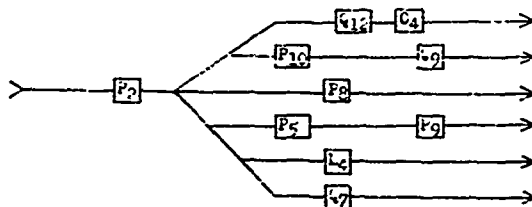
4.23 All the paths which have been listed so far have started with the event P_2 that the 2 second actuator breaks it confinement and initiates a primer. There are other ways in which the primers can be initiated. The primers have high electrical sensitivity, and although the fuze circuit is designed to isolate the primers and numerous electrical checks are made during assembly to preclude wiring errors, there is still a possibility that bad wiring was missed or that subsequent treatment induced a fault which would permit the charging current to fire a primer. These and other considerations, such as shock, R. F. induced current, etc. are included in the event C_1 that the primer is actuated spuriously. Since the event C_1 associates with primer firing, it will be followed by the events previously presented involving defeat of the safety provided by the rotor. As a second part of the diagram, we have:
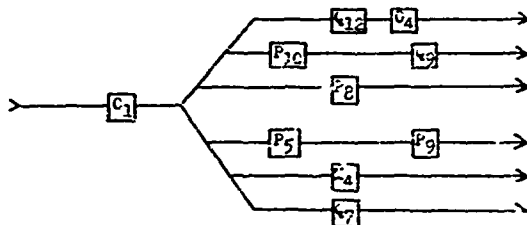
The result of a continuation of this process is given in Fig. 4-4. The events appearing in this figure are defined in Table 4.1.

4.24 Events having probabilities which are nearly equal to
1.0 are omitted from diagrams. In combination with the many
small probabilities of events which usually make up a path,
these large probabilities have very little effect on the value
of the final answer. Furthermore, since in most cases the bases
for estimates of values are not good enough to arise departure
from the use of a decadal system, values such as 0.8, 0.9 etc.
would generally be carried at 1.0 and will not change the path
value. For example, in Fig. 4-3, P_2 is the event that the

2 second actuator initiates a primer. Although this event is
considered as the start of the path, there are certain things
which must occur before the actuator fires. Switches must
close; power must be available. None of these are certainties
(i.e. probability equal to 1.0), but since they are involved
in normal functioning, these probabilities are probably of the
order of 0.9 or better. Because these events have so little
effect on the path answer, they are omitted or tacitly
included in other events, thus simplifying the diagram.

4.24 It will be noted that in Fig. 4-4 there are numerous
duplications of events. For example, E_4, G_7, F_9, G_9, C_1, C_5,
and T_{10} appear four times; G_1, G_{11}, and G_4 appear three times,
etc. In the final diagram, it is desirable to have no
duplications, for an event is discrete. Furthermore, dupli-
cations tend to increase the difficulty of determining the
valid cross products which apply to correct the answer obtained.
However, the preparation of a work sheet, such as Fig. 4-4
with its numerous duplications, is a recommended step in the
preparation of a diagram.

4.26 Experience has proved that the following steps are best
suited to the orderly preparation of a situation diagram.

a. Step 1. Accident Paths. The first step in the prepa-
ration of a diagram is to set down individual accident paths.
At this time it is wise to disregard duplication which is
occurring so that full attention can be directed to the nature
of the events and the factors which affect them. At no other
time is the device itself under greater scrutiny. It is
pictured in the light of experience, aided by imagination, in a
situation and the events which could lead to accidents are set
down as they come to mind. The result is a work sheet some-
thing like Fig. 4-4 At this time any concern regarding the
final appearance of the diagram is apt to detract from the
thought with which each path is considered and reduce the care
exercised in exploring all possible avenues.

b. Step 2. Systematic Combining. Step 1 may result in little system or order in the way the accident paths are listed. Step 2 is rarely mechanical and involves ordering and combining paths to reduce duplication and the size of the diagram. It will usually be found that one initial event will lead into a number of other events so that the paths tend to branch. This is illustrated in Fig. 4-4 where the initial events are not repeated, as they well might be in a first work sheet. Removing duplication in initial events is actually a part of step 2, but is usually so simple that it is done in step 1 without causing any distraction. Removing duplication in later events in the accident path chain requires a little more manipulation. Figs. 4-5 and 4-6 illustrate stages in the process of combining paths. It will be noticed that many duplications have been removed in Fig. 4-6 and that only C_{11}, C_1 and O_5 are duplicated in Fig. 4-3 which is considered one of the simplest practical diagrams for this situation.

c. Step 3. Assessing Duplication. It is often difficult to remove all duplications of events and come up with a diagram which is easy to follow. In Fig. 4-3 duplication has been permitted to remain because removal would require complicated crossing lines and otherwise modifying existing rules (which will be discussed later). Duplication is undesirable because in the full expansion of the terms it will introduce terms which are incorrect and, in the rigorous sense, non-existent. However, in the practical use of the RAP Analysis it is quite unlikely that these terms will affect the usable part of the probability factor. In the event there is a question, it is always possible to write down the terms and determine where the incorrect products affect the answer. Guides to writing cross product terms will be found in Appendix A.

4.27 When duplication is allowed to remain, it is advisable to note this on the diagram as done on Fig. 4-3. This makes the problem of picking out appropriate cross products considerably easier. In the more complicated diagrams a reasonable amount of bridging of lines will not remove all duplication. The balance between optimum bridging and duplication is a matter of judgment. Too much bridging makes the diagram extremely hard to follow. Too much duplication leads to inaccuracies in the study of cross product effects.

4.28 It will be noted that all the lines joining different levels in the diagram of Fig. 4-3 are slant or. These slanting lines serve a particular purpose. They are unidirectional

from left to right. In following an accident path it is
permissible to enter a slanting line provided this line still
gives motion to the right. This is illustrated in Fig. 4-3
where we note that the path P_2L_4 satifies the requirement,
but the path P_6O_4 would require reversing direction on a
slanting line. Referring to Fig. 4-4 we see that P_2L_4 is a
valid path, but P_6O_4 is not. If the line joining the two
portions of the diagram had been drawn vertically, there would
be no way to make this distinction.

4.29 The events which make up a situation diagram are usually
a mixture of independent events and mutually exclusive events.
Independent events are those which can occur independently of
any other events. One independent event does not preclude
another; the two can co-exist. For example, in Fig. 4-3,
P_3 and Q_4 are independent for all practical purposes. The
actuation of a primer by the actuator is considered to be
completely independent of the closure of the reel switch. These
independent events give rise to cross products. The product
P_3Q_4 exists. Mutually exclusive events are events which cannot
co-exist; one event precludes the other. In Fig. 4-3 Q_9 and
P_8 are mutually exclusive events, i.e. the event that the
primer fires a lead with the rotor in the safe position does
not exist if the rotor was never installed. Since the cross
product is a correction for the simultaneous occurrence of
events (paragraph 4.6), mutually exclusive events do not have
cross products. However, there is a factor linking the
mutually exclusive events. If we consider the probability that
the rotor is absent and the probability that the rotor is
present, it is apparent that these two must add to 1.0. In
assigning probability values to the events in Fig. 4-3, it
should be realized that the value of p_8 should be multiplied by
$1-q_9$ to correct for those times when the rotor is absent. But
the value of $1-q_9$ is 0.99 (Fig. 6-1) and it contributes nothing
to the answer. It will usually be found that this factor can
be omitted because it is too great a refinement for the system
employed.

4.30 In practice the demarcation between independent events
and mutually exclusive events is usually not very clear. In
the example given in the last paragraph, it could be argued
that the firing of a primer might create disturbances which
would influence the closure of the reel switch and thus the
two would not be truly independent. In general, if action

diagrams do not attempt to distinguish between independent
events and mutually exclusive events.* It has been found more
profitable to consider these problems when the effects of the
larger cross products are being assessed. This will be dis-
cussed in detail in Chapter 6.

4.31 In summary, the situation diagram is a graphic presenta-
tion of the accident paths so arranged that individual paths
are clearly discernible and the relations of paths to each
other are depicted. It is a map of the routes through which
safety can be defeated where each event is identified by a
symbol having an assigned probability value.

* In very simple diagrams a symbology has been used to
note the difference between independent and mutually exclusive
events. This is illustrated by the following example.
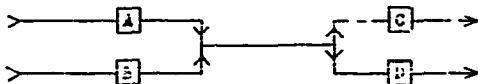
A and B are mutually exclusive, and to signify this their paths
are joined by vertical lines. Permissible motion on the
vertical lines is indicated by arrows. C and D are also
mutually exclusive. The equation for this simple diagram is
$(a + b)(c+d)$. In this scheme events which are independent
would be joined in the normal manner by slanting lines.

TABLE 4.1

EVENT DEFINITIONS

Situation "1" - Normal Drop From
Bomb Release to Safe Separation

Event Symbol	Event Definition
M_4	Rough handling mechanically arms rotor.
O_1	50 ms or instantaneous primer actuated spuriously.
O_4	4-1/2 sec. actuator (A_2) spuriously initiated.
O_5	A detonator is spuriously initiated.
P_2	2 sec. actuator (A_1) initiates a primer.
P_3	4-1/2 sec. actuator (A_2) initiates a primer.
P_5	Primer fires detonator - rotor in safe position.
P_6	2 sec. actuator (A_1) fires a detonator.
P_7	4-1/2 sec. actuator (A_2) fires a detonator.
P_8	Primer fires a lead-rotor in safe position.
P_9	A detonator fires a lead-rotor in safe position.
P_{10}	Primer fires a lead-rotor absent.
P_{11}	2 sec. actuator (A_1) fires a lead.
P_{12}	4-1/2 sec. actuator (A_2) fires a lead.
P_{13}	4-1/2 sec. actuator (A_2) fires lead-rotor absent.
Q_1	2 sec. actuator (A_1) gives very short or no delay.
Q_4	Reed switch in fast primer circuit (R-SW-1) is closed or closes.
Q_7	Rotor arms because of missing shear-wire.
Q_9	Rotor is missing (never installed).

TABLE A-1 (Cont'd)

| Event Symbol	Event Definition
G_{11}	4-1/2 sec. actuator (A_2) gives very short or no delay.
G_{12}	Rotor lockshaft short or missing.
T_8	The transform which corrects for the probability values of C_1, C_5, and G_4 which are based upon 6-1/2 seconds (the time in which a premature is considered dangerous) to comparable values for 2 seconds. The transform T_8 accounts for the fact that A_2 has a normal delay of 4-1/2 seconds leaving 2 seconds for accident.
T_9	The transform which corrects for the probability values of C_1, O_5, and G_4 which are based upon 6-1/2 seconds to comparable values for 4-1/2 seconds. The transform T_9 accounts for the fact that A_1 has a normal delay of 2 seconds leaving 4-1/2 seconds for accident.
T_{10}	A_2 arms rotor before firing primer or detonator.
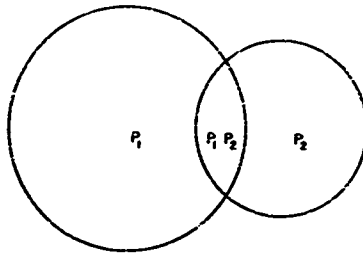
FIG. 4-1   INTERSECTION OF TWO EVENTS
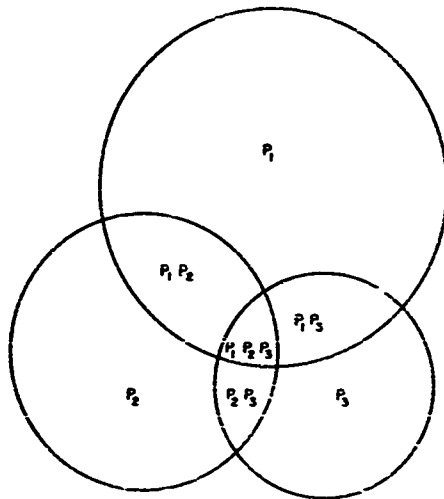
FIG. 4-2   INTERSECTION OF THREE EVENTS
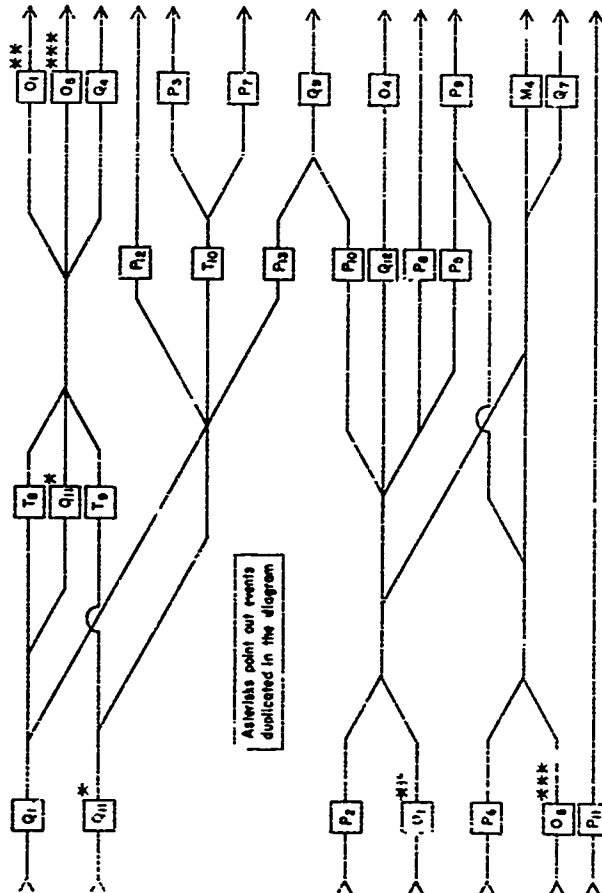
FIG. 4-3 · DIAGRAM OF SITUATION "1"

Asterisks point out events duplicated in the diagram
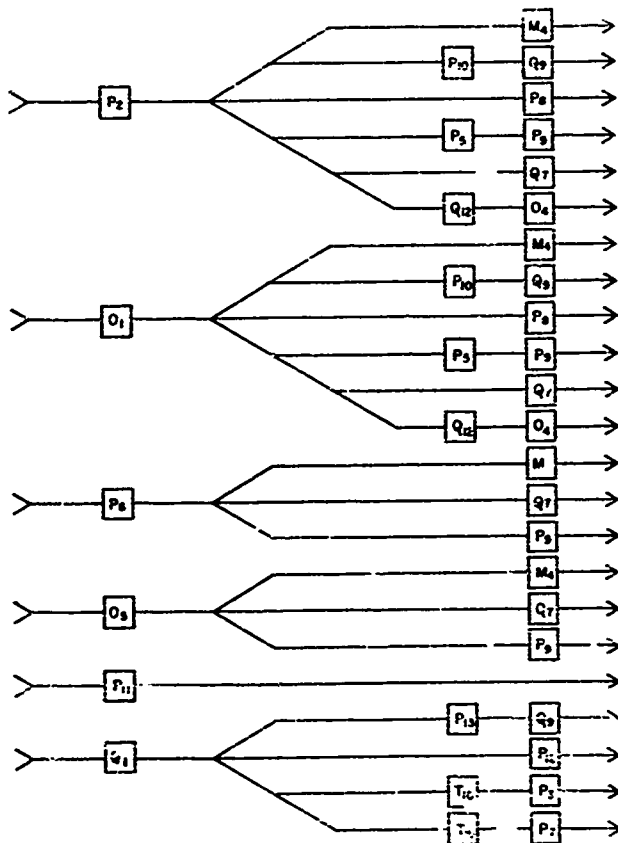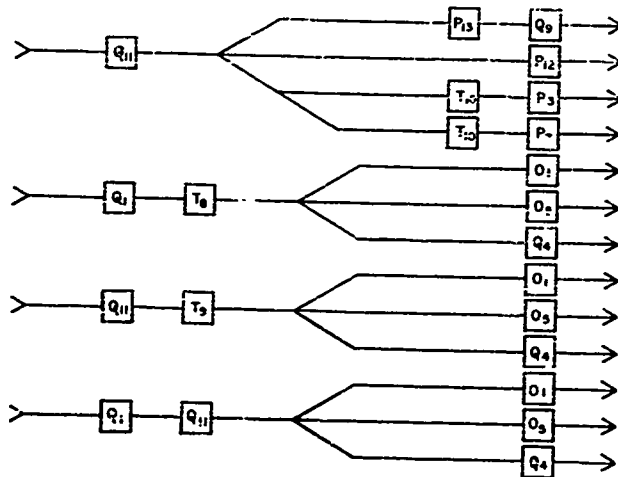
FIG 4-4 PREPARING A DIAGRAM, STEP 1

FIG. 4-4   CONTINUED
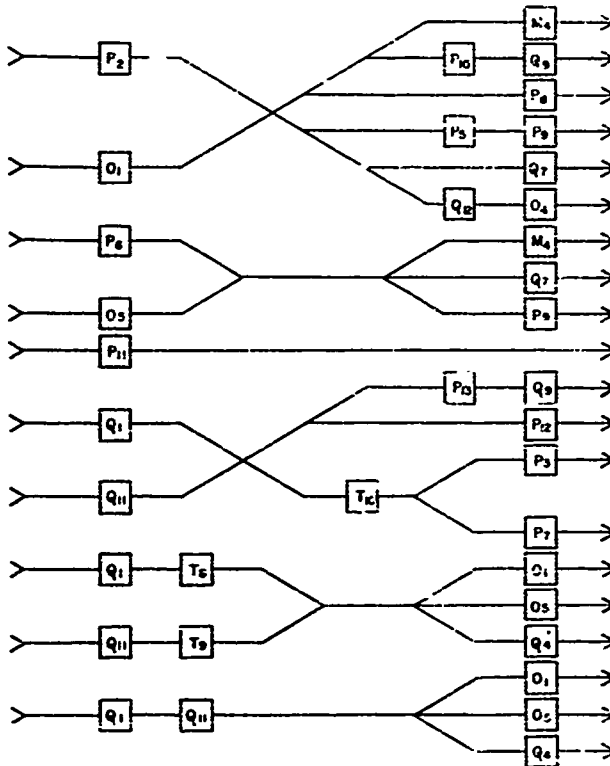
FIG. 4-5 PREPARING A DIAGRAM-
STEP 2 ELEMENTARY
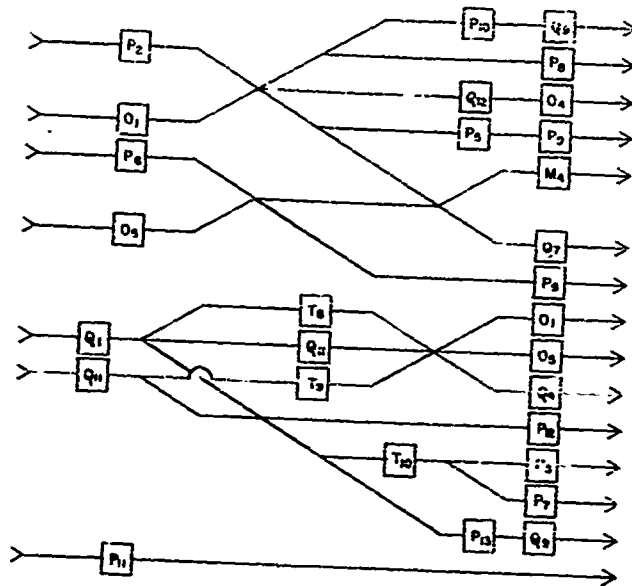
FIG. 4-6 PREPARING A DIAGRAM -
STEP 2 ADVANCED

CHAPTER 5

PROBABILITY ASSIGNMENT

5.1 Having obtained in the diagram a graphic picture of the
routes and events which will lead to accidents, the next major
step in the analysis is to assign numerical values to the
probabilities of occurrence of these events. Off-hand, this
would appear to be a difficult task. This, however, is not the
case if the persons making the assignment have a general,
practical knowledge of ordnance and of the "situation" under
consideration and will earnestly seek knowledge obtainable
from the experience of others in service use of similar items
under related conditions. Also many quantitative values can
be obtained directly from test results of the device under
consideration or of similar devices. Only in part of the cases
will it be necessary to arbitrarily assign values.

Arbitrary Assignments

5.2 It is realized that in arbitary assignments, it is unlikely
that two people would assign the same probability of occurrence
to a specific event. In the final results, which are generally
used only in the relative sense, this may make very little, if
any, difference if the individual values are selected on a
comparative basis and consistency is maintained through cross-
checking of related events. If more than one person is
assigning probability values to the various situations, it is
advisable that those persons as a group review the values for
all the situations so that the assigned values for each of the
situations and events are made on the same basis or from a
common reference point. Sources of information which may be
useful in assigning probability values are: QC reports on
similar service ordnance; statistical data from fleet oper-
ations; test and evaluation data; and Acceptance Quality Level
assignments stated in the design disclosure documents governing
manufacture.

5.3 In assigning a numerical value to the probability of the
occurrence of an event, it is desirable to use a decadal
system. That is, the probability is set equal to 1×10^{-x},
where the exponent, an integer, is the number to be assigned.
This method has several advantages. It is relatively easy to
decide or determine if a probability is nearer to one occur-
rence in 10 (10^{-1}), or 1 in 100 (10^{-2}), or 1 in 1000 (10^{-3}),
etc., while in most cases it would be difficult, in a pre-
liminary analysis, to assign values with an accuracy greater

than a factor of ten. Also, if the diagrams are complicated and lengthy and there are a large number of situations, the computations become much simpler with such a system. After the analysis is completed, it is known which values are critical in respect to the overall answer. Then these values may be examined more closely and a more accurate figure may be obtained through further investigation, or as a result of an evaluation program or from other additional data which may be obtained by increased effort.

Systematic Scheme of Assignment

5.4 In order to assign values which are as realistic as possible, it is necessary that it be done in a systematic manner. Since the various events have been broken down into groups (see para. 4.11 and 4.12), it is desirable to assign probability values by groups rather than to individual events encountered in a situation diagram without regard to similar events occurring in other situations. This means that it is highly desirable that <u>all</u> of the diagrams be completed before an attempt to assign any probability values is made; the advantages can readily be seen as values are assigned in the example. On the other hand, <u>no attempt should be made to guess in advance which values are going to turn out to be the critical ones</u>, as this would probably affect and bias the accuracy of the analysis.

5.5 While it is best to assign the probability to an event in all situations at one time, it should be noted that the probability of occurrence may or may not be the same for the same event in the various situations. It so happens that O_1 has six different values throughout the situations of the example fuze while C_7 has only one value. This is logical since O_1, which is the spurious actuation of the 50 ms or instantaneous primer, is highly dependent upon the environment which frequently makes different situations. On the other hand, C_7, which is the event that a missing shear wire allows the rotor to arm, is the result of an assembly error and has little, if any, dependence upon the environment existing in a situation. Other events, such as S_7, which is the accidental pushing of the bomb release button, may occur in a very few of the situations (3 in this analysis).

Example Probability Values

5.6 The assigning of values may best be described by an actual illustration. For this step in the analysis, a work sheet like Table 5.1 may be used; the various situations are listed across

the top and the events down the left side. It is advantageous
to have the work sheet complete with all the events listed.
This makes it much easier to cross-check the probability values
as they are assigned. For this example, we will work with the
group of events designated by the symbol O. There are five of
these events as shown in Table 5.1. In the first event, O_1,
(spurious initiation of 50 ms or instantaneous primer) in
situation "a", (assembly, packaging, storage, handling, and
transportation outside of ordnance - this includes all
situations before the bomb and fuze are associated, from loading
plant to ship's magazine, to unpacking just prior to fuzing) we
will assign to x a value of 3. This means the probability of
O_1 occurring is one in 1000 (1/1000). At first thought, this
value of x may seem very large, but it must be remembered that
this situation may cover a lot of time and "ground" - from
loading plant to use.

5.7 For the most part this assignment was arbitrary, but there
were some facts which could act as guides in getting the proba-
bility into the right order of magnitude. The most sensitive
wire-bridge primer which has been produced in large numbers is
in the class known familiarly as the ND-24. Total production
of this class of primer for fuze and other uses runs well into
the millions. The history of use of this primer is spotted
by unintentional actuations, some of known but many of unknown
causes. Although the records do not lend themselves to easy
determination of the rate of accidents in fuze assembly and
handling it must be assumed that these operations had their
share. Because of the fact that numerous stories of spurious
actuations of the ND-24 primers had come to light, it was felt
that the rate must be somewhere between 10^{-4} and 10^{-5}. In the
face of the stories and reports, it did not seem reasonable to
assume that, on the average, more than 100,000 of these primer
could be assembled into fuzes without at least one accident.
The primers used in the Bomb Fuze EX-200 are about 20 times
more sensitive to capacitor discharge than the ND-24 and about
twice as sensitive to direct current initiation. It must be
assumed that these primers would be involved in an even greater
number of incidents. For this reason, the value of 10^{-3} was
assigned as the probability that the instantaneous or 50 ms
primer would be spuriously initiated.

5.8 In the second event, O_2, the same value (3) is assigned
since this primer is similar to the other two and has the same
sensitivity. In the third event, O_3, the actuator is more
sensitive or more susceptible to spurious initiation than the
primers; therefore a value of 2 is assigned to x (1/100). In

Best Available Copy

O_4 the value is the same as C_3 since the sensitivity of the
actuators is the same. In O_5, since the detonator is not as
sensitive or susceptible to spurious initiation as the
actuators or the primers, a value of 4 is assigned to x. This
and the preceding paragraph have illustrated the process of (a)
determining with the best information available a reasonable
value for the occurrence of a key event, and (b) using this
key event as an anchor point reconciling the values assigned
as the probabilities of other related events.

5.9 Now we are ready to assign values for the next situation
which is Fuzing - inserting the fuze in the bomb. This
situation differs from situation "a" in that the time required
to remove a fuze from its container and to place it in the fuze
well of the bomb is only a matter of minutes for a normal
operation. Thus, any occurrences which depend on time will be
minimized. Also, a fuze which has been removed from its
shipping container will be handled more carefully than one in
the container. The following values will be assigned: 6 for
C_1, and O_2, 4 for O_3 and O_4 and 7 for O_5. Situation "c" is
concerned with defuzing of the bomb for any reason. The
probability values for the various events in this group are
considered to be the same as for situation "b". In situation
"d" (handling of the fuzed bomb), the handling of a fuzed bomb
will be even more careful than the handling of a fuze; the fuze
is more protected and it is less likely that the fuzed bomb will
be dropped; therefore, higher values will be assigned to x for
the events in this situation. The assignment of numerical
values for the events of other situations is done in a similar
manner.

5.10 For events such as q_7 (missing shear wire permits rotor
to be in armed position prior to operation of arming actuator)
which are a function of the initial assembly of the fuze, the
value will logically (at least as a first approximation) be
the same for all situations considered. This probability is
typical of many in that it can be further broken down into two
series probabilities. One is that the wire is missing (from
omission in manufacture in this case, since the design of this
fuze is such that it will not fall out once it is in place)
and the second is that at any particular time the unrestrained
rotor may be in such an angular orientation that it will permit
fire-through. In the assembly of the fuze the absence of the
shear wire would, under rules presently in effect, be con-
sidered a critical defect and therefore the inspection of this
part would be more thorough than for some other part of the fuze
Also, the method of rotor assembly gives greater assurance that
the shear wire is not missing. Independent estimates of the

frequency of a missing shear wire during manufacture have ranged from 1/2000 to 1/10000. For this example we will say 1/4000 (1/4 x 10^{-3}), which seems quite realistic. The rotor serves as the interrupter for the explosive train and during the arming period it rotates 90 degrees from the unarmed position to the fully armed position. However, the explosive train will reliably fire-through when the rotor is in a position 28 degrees from the fully armed position. (This is determined by explosive train reliability tests in the laboratory.) Therefore, if a rotor were not restricted in its rotational movement and there were no unbalance tending to orient the rotor in any particular attitude under normal vibration or jolting, a random distribution of angular displacement might be assumed. Under these conditions it could be said that the rotor would be in a fire-through position 28/90 of the time. However, since the rotor is unbalanced and has a tendency to remain in the unarmed position during vibration or jolting when the fuze is in the vertical, booster-down position, we will say that the rotor would be in a fire-through position 1/2 x 28/90 of the time. Thus, the probability that a missing shear wire will result in an armed fuze is 1/2 x 28/90 x 1/4 x 10^{-3} or $(3.89)10^{-5}$.* Putting this into the decadal system, as explained in the following note, we get 1 x 10^{-4} which will be used as the value for C_7 in all situations.

* The rule used for "rounding-off" in the decadal system when an actual estimate of a probability is given is determined by at least squares criteria in the logarithm of the probability. It is as follows: The given estimate is written in the form K x 10^{-x}, where x is a positive integer and $1 < K < 10$. Then, if K is less than 3.162, the estimate used in the analysis is given as 10^{-x}. If K is greater than 3.162, the estimate used in the analysis is given as 10^{-x+1}. As an example, if an estimate were given as .000273 which equals 2.73 x 10^{-4}, the value to be used in the analysis is 10^{-4}. If the estimate were given as .000367, the value to be used would be 10^{-3} since 3.67 > 3.16. In an analysis of this type where products of the individual terms are the end result, this form of rounding off will result in the least dispersion of the result from the term value.

5.11 For other situations and for other groups of events,
the values are assigned in the same manner. In this analysis,
a value of 7 was the largest assigned. It can be seen in
Chapter 6 that a higher value of the exponent would have very
little, if any, significance after the multiplication of the
series probabilities in a path. Furthermore, it is felt that
predicting a probability of occurrence of one in ten million
for a single event is certainly enough of a strain on the
interpretation of data, and that, although probabilities of this
magnitude and smaller may actually exist, it is unreasonable to
believe that normally these will be good enough bases for
predicting them.

Reason for Pessimistic Assignments

5.12 There is one other basic rule which should be followed.
In the case of those probabilities whose assignment is based on
little experience and data, the value used in this first
approximation should be the highest considered likely or
possible. That is, if there is no basis for saying that an
event probability is any greater than 1×10^{-7} nor, on the other
hand, that it is any less than 10^{-2}, the 10^{-2} value should be
used. If it turns out that the overall hazard terms in which
this probability plays a part are small, nothing has been lost.
If it is significant, a better value can be obtained by greater
effort in a second-approximation analysis. On the other hand,
if a low probability (high exponent) had been selected and the
event should later turn out to be more frequent, its signifi-
cance to the analysis result would have been missed.

5.13 Other examples of the reasoning behind the choice of
probability values in another analysis are given in Appendix B.

TABLE 5.1

EXAMPLE PROBABILITY VALUES

Values of X for Probability Value = 1×10^{-x}

Events \ Situations	a. Storage	b. Fusing	c. Defusing	d. Handling	e. Connecting to plane	f. On deck before take-off	g. Take-off	h. Flight	i. Normal drop	j. Ret. & Normal Landing	k. Return-Hung Bomb	l. Crash-Hung Bomb	m. Crash-Normal Ord.	n. Disposal	o. Removing Bomb
O_1 Spurious initiation of 50 ms or instantaneous primer	3	6	6	7	5	7	6	6	•	6	3	2	2	5	7
O_2 Spurious initiation of 11 sec. primer	3	6	6	7	5	7	6	6	-	6	3	2	2	5	7
O_3 Spurious initiation of 2 sec. actuator(A_1)	2	4	4	5	5	5	4	4	-	4	3	2	2	-	5
O_4 Spurious initiation of 4-1/2 sec. actuator (A_2)	2	4	4	5	5	5	4	4	3	4	3	2	2	4	5
O_5 Spurious initiation of detonator	4	7	7	7	7	7	5	7	7	5	3	2	2	5	7
G_7 Missing shear wire results in an armed fuze	4	-	4	4	4	4	4	4	4	4	4	4	4	4	4

CHAPTER 6

SUMMATION OF PATH PROBABILITIES

6.1   Table 5.1 lists the probability values associated with the "O" events (see 4.11) occurring in all situations of the RAP Analysis of the Bomb Fuze EX-200.   In a complete RAP analysis similar tables would be prepared for all events.   As explained in Chapter 5 these are exponents for the base 10 and are listed in this manner to take advantage of the easier computations of the decadal system.   These values are plugged into a situation diagram to obtain the probability factor. To illustrate this, the probability factor for situation "1", which appears in Fig. 4-3. will be computed. .

Preparing the Work Sheet

6.2   The top path in Fig. 4-3 is $q_1 t_8 o_1$.   This is a series path, and its probability is the product of the probabilities q_1, t_8 and o_1.   From tables like Table 5.1, we would find that q_1 carries the exponent 2, t_8 the exponent 1 and that o_1 carries the exponent 4.   This means that q_1 has been assigned the value 10^{-2}, t_8 the value 10^{-1} and o_1 has the value 10^{-4}.   The path probability in accordance with the simple rule for series events given in 4.2, is the product of these individual probabilities and has the value 10^{-7}.   This was obtained by simply adding the exponents.   This illustrates one advantage of the decadal system.

6.3   The second path in Fig. 4-3 is $q_1 t_8 o_5$; the third path is $q_1 t_8 o_4$; the tenth path is $q_1 p_{13} o_9$.   Table 6.1 lists the 36 paths taken from the normal drop situation, (Fig. 4-3).   It is a work sheet used in the determination of the probability factor.   The symbol for the probability of occurrence of each event is listed separately in each path in which it appears, and under each is placed the value of the exponent obtained from Table 5.1 and similar tables for other events.   The path probability exponents appearing in the right hand column are the sums of the exponents appearing in the rows, obtained as in 6.2.

The First Approximation .

6.4   All the paths or rows are in parallel.   The combination of these to obtain a situation probability factor involves the use of the equations for the probabilities of parallel events

(Appendix A). The equation for the combining of the probabilities of two parallel independent events is given in paragraph 4.2 and is $p = p_1 + p_2 - p_1 p_2$. When two events are exclusive the equation is $p = p_1 + p_2$. Although these equations are much simpler than an equation for 3 parallel paths they do illustrate that the first order terms are simply added. This is the first step in the summation of path probabilities; i.e., $p = p_1 + p_2$ is taken as a first approximation of $p = p_1 + p_2 - p_1 p_2$ when it applies, and as illustrated in paragraph 4.8, this is often a satisfactory approximation.

6.5 Summing the path probabilities to obtain a first approximation of the probability factor for the situation is quite simple as long as the decadal system is employed. For example, $10^{-8} = 0.00000001$; $10^{-8} + 10^{-8} = 0.00000002$; and $10^{-6} + 10^{-8} + 10^{-8} = 0.00000102$. It will be noted that the appearance of the exponent -8 placed a unit in the eighth place to the right of the decimal; the addition of two path probabilities of value 10^{-8} placed two units in the eighth place; and the addition to this of the value 10^{-6} placed a unit in the sixth place. If a table is set up with exponent column headings, the probability factor for a situation will be obtained as a decimal fraction simply by placing the number of path probability exponents under the appropriate columns remembering, of course, that each time 10 or a multiple of ten is reached, the column to the left is increased. A table of the data obtained from Table 6.1 is given below.

0	DECIMAL	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	.	0	0	1	1	1	1	4	9	6	6	3	2	1	1

This table shows that under the path probability column of Table 6.1 there was 1 - three, 1 - four, 1 - five, 1 - six, 4 - sevens, 9 - eights, etc. Of course, this same result could have been obtained if there had been no - sixes and 4 - sevens. All exponents are negative.

6.6 The first approximation of the probability factor can be carried as it appears in the table or can be shifted to other decimal units. Since an accident rate of one in one million is a goal in fuze design, it seems advisable to carry the answer in millionths. The approximation of the probability factor in the example given then becomes 1111.49×10^{-6}. Table 6.2 is the probability factor approximation work sheet for all situations involving the EX-200 bomb fuze. The figures were obtained by the processes described in the above paragraphs.

6.7 In Table 6.2 the probability factors are carried out to the exponent 16 (i.e. to 10^{-16}). It is apparent that many of the places carried are not significant and that the subtraction or addition of the larger cross product terms would change figures far to the left of the 16th place. However, there is one advantage in carrying a lot of apparently meaningless places in the work sheet. If some change is made in the device, the direction of the effect can be observed by simple addition or subtraction no matter how small it may be. But it must be remembered that it is not correct to state that the probability of accident in situation "a" is 3.3224471×10^{-6}, for such a statement implies an accuracy which is known not to exist in the first approximation.

Magnitudes of Errors

6.8 At this stage in the analysis arriving at a numerical value which is sufficiently accurate to be quoted as the probability factor for the particular situation requires three basic steps. These are: (a) a critical review and re-evaluation of the path or paths which contribute the greatest amounts to the numerical values of the first approximation, (b) a review of the effects in these paths of rounding-off values as part of the decadal system, and (c) an assessment of the corrective effects of cross products. Step (a) is necessary since, as pointed out in Chapter 5, many of the probability values are assigned on the basis of personal opinion or judgment. Assuming there has been reasonable consistency in the personal trait of optimism or pessimism which influenced the judgment in assigning these values, the paths which contribute the most to, or actually control the magnitude of the probability factor are the more likely causes of accidents and therefore should be the focal points of study or testing. This step is therefore a "second look" to see if there is substantial background for these influential choices. Step (b) is to determine if the system of rounding-off recommended with the

decadal system has biased the results to the extent that the path appearing to be the most likely cause of accident actually is not. For example a value of 1/300 based on test or actual experience would be rounded-off to 1/100. If this were to happen several times in a path, the path answer could be affected by a factor of 10. Step (c) is a more mechanical step. Its primary purpose is to obtain an idea of the magnitude of the error in the answer which is attributable to lack of rigorous mathematical treatment. In this step the larger cross product terms may be applied to the answer or may be ignored after it has been established to what extent they influence the answer. The step also includes decisions regarding the existence or non-existence of cross products, and therefore requires that the relationships of the events be classified as either independent or exclusive (4.29 and Appendix A).

6.9 Situation "1" will again be used as the example illustrating steps of the analysis. In Table 6.1 it is noted that the path $q_{11}T_9q_4$ has a probability greater than any other path. q_{11} is defined as the event that the 4-1/2 second actuator burns very fast or gives no delay. q_4 is defined as the event that the reed switch in the instantaneous primer and 50 millisecond primer circuit is closed or closes. T_9 modifies the probabilities based on 6-1/2 seconds since the accident can only occur in 4-1/2 seconds. Since it is rounded off to 1 it does not contribute to the path value. The combination of these events would cause bomb explosion before safe separation had been attained. This is clarified by reference to Fig. 3-1. The delay provided by the 2 second actuator will allow the bomb to fall some distance from the plane but since the designed safe separation time is 6-1/2 seconds this is obviously not yet a safe distance. If then the 4-1/2 second actuator gives no delay and closes the primer circuit in which the reed switch is already closed the bomb will explode two seconds after release. Short burning of the 4-1/2 second actuator is a variation which would permit more, but presumably not enough, separation of bomb and airplane at the time of detonation.

6.10 The probability q_{11} was assigned the value 10^{-2}. This means that on the average it was felt that one in a hundred of the 4-1/2 second delay actuators would burn through very rapidly or give no delay. This rather pessimistic estimate may be based on a distrust of pyrotechnic delays or bad experience with some such delays or a combination of both. Experience with pyrotechnic delay columns has indicated that these delays usually either give a reasonable delay time or

else "fire through" without delay. This tendency to "fire through" appears to relate to such factors as vigor of initiation, nature of confining walls, and delay column length. Thus great variations in this regard can be expected from different physical arrangements, and the tendency for any particular delay element to "fire through" must ultimately be judged on the basis of its performance. Lacking such information the figure of 10^{-2} was selected on the basis of test work performed on two delay cartridges, one having a nominal delay of two seconds and the other a delay of five seconds. Although these delay cartridges are initiated by a percussion primer and also differ in other physical aspects, there seemed to be too little evidence to assume, at this time, that the delay actuators of the bomb fuze would be less likely to "fire through". In 1049 tests of the two second delay cartridge seven "fired through" thus giving a best estimate of 1/150 on the average. In 283 tests of the five second delay cartridge two fired through thus giving a best estimate of 1/141. The value of one in one hundred was therefore assigned to adhere to the decadal system. Someone having more confidence in this particular design might have chosen a figure like 10^{-4} or 10^{-5} and in either event this would have a marked effect on the value of the probability factor. If these two people were to get together, they might settle on an intermediate value, but the point that is brought out is that this is an area in which testing is important. Unless the estimates are actually ludicrous the RAP Analysis will point to the areas of danger which require attention through remedial measures or proof that the opinions involved were far too pessimistic. Because of the curtailment of this fuze development the burning times of these specific actuators were not adequately checked and the estimated value of q_{11} remains doubtful.

6.11 The other event of interest in this path is q_4. The value of 10^{-1} assigned to q_4 was based on some knowledge of the sensitivity of the switch. Tests demonstrated that these switches could be functioned by drops of a fraction of an inch. Lacking, however, is sufficient information on the types of shocks or internal vibrations which the bomb might encounter in flight, the frequency with which bombs may be expected to bump other bombs, and the probability that switches will be defective through premature closure. Thus q_4 may also be a pessimistic estimate which would be improved if all the facts were known. The value of re-examination of the path is to (a) confirm that the path is a valid accident path, (b) show where more effort should be placed in the gathering and analysis of

available information or in testing and, (c) note how changes can improve the situation. In the example given, there is considerable doubt that the path is as dangerous as these figures indicate. But if we assume that these figures are substantially correct, the analysis shows that much improvement in this individual situation can be obtained by (1) use of a less sensitive switch, and/or design of switch to reduce the possibility of closure as a defect, and (2) increasing the reliability of the delay time.

6.12 The inspection of paths for the effects of rounding-off is most useful when two paths have the same value, for by this process it may be possible to determine which of the two paths is the slightly more probable cause of accident. For paths of nearly equal value to differ by a factor of 10 in the decadal system requires an unfortunate combination of rounded-off values in one or both of the paths. The examination of all events relative to each other for the effects of cross products is a tedious process which usually yields too little to justify the work involved. The probability factor for situation "1" determined with the consideration of all cross products (Appendix A) differs only slightly from the first approximation. In general the consideration of the effects of rounding-off and of the Exposure and Severity Factors should be undertaken before any cross-product study is made since these effects will usually overshadow any cross-product terms.

6.13 The process of checking the effects of cross-products can be greatly simplified when only the largest paths are considered. The significant products will usually come only from the high probability paths. The largest contributions to the probability factor approximation of situation "1" come from the paths containing the events c_1, c_{11} and q_4 (Table 6.1). The chances are very good that the largest cross products will come from combinations containing q_1, q_{11} and/or q_4.

6.14 The first step is to assume that the events appearing in paths parallel to the path of highest accident probability are independent of the events in the path of highest probability and therefore have cross products. From Table 6.1, we find that the two most important paths are $c_{11}Tq_4$ (10^{-3}) and c_1Tq_4 (10^{-3}). Referring to Fig. 4-3, we see that these paths, if independent, would combine to give a cross product $q_1t_8q_{11}t_9q_4$ with a value of 10^{-6}. If the assumption of independence is correct, the first approximation probability factor for situation "1" (Table 6.2) would, by this one cross product, be corrected to 1110×10^{-6}. However, to check the assumption of independence,

It is necessary to examine the definitions of events. These are given in Table 4.1.

6.15 For all practical purposes, it seems reasonable to consider q_1 (short or no delay of 2 sec. actuator), q_{11} (short or no delay of 4-1/2 sec. actuator), and q_4 (reed switch is closed or closes) as independent. But on examining the definitions of T_8 and T_9, we find that by definition T_8 requires that event q_1 and not Q_{11} occurs and that T_9 requires that event q_{11} and not Q_1 occurs. These T's establish the mutual exclusiveness of the paths considered and the cross product considered in the above paragraph does not exist. In retrospect this is quite apparent. In the diagram (Fig. 4-3), we note that in addition to the paths we chose for first consideration, there are three paths containing q_1q_{11}, viz. $q_1q_{11}o_1$, $q_1q_{11}o_5$, and $q_1q_{11}q_4$. The fact that a special path was put into the diagram to give the q_1q_{11} combination was in itself a "red flag", for the coexistance of q_1 and q_{11} would be automatic if the two paths containing q_1 and q_{11} singly had been independent. We note that further down in the diagram this independence is recognized. For example, the cross product $q_1q_{11}p_{12}$ exists.

6.16 Continuing with the investigation of the highest probability paths, it is necessary to examine the cross products resulting from the combining of o_1o_5, o_1q_4, and o_5q_4. The largest cross product coming from these is $q_{11}t_9o_1q_4$ with a value of 10^{-7}, and the next largest is $q_1t_8o_1q_4$ with a value of 10^{-8}. The product $q_1q_{11}o_1q_4$ has a value of 10^{-9}. Consideration of the definitions of o_1, o_5, and q_4 leads to the conclusion that there is no reason not to consider them as independent. A continuation of this process will show that there are no other cross products which contribute as much as 10^{-7} to the probability factor. The cross products considered will change the probability factor of situation "1" from a first approximation of 1111.496×10^{-6} to 1111.385×10^{-6}.

6.17 As mentioned in paragraph 6.12, the effects of rounding-off values to remain in the decadal system may have far more effect on the value of the probability factor than the cross products. A good example of this is found in the T_8 and T_9 events appearing in situation "1". These events were defined as transforms with the exact values of $2/6-1/2$ and $4-1/2/6-1/2$ which were rounded-off to 0.1 and 1.0 respectively. Neglecting

cross products entirely we will examine the effect of rounding-off these values. T_8 appears in three paths; viz. $q_1 T_8 O_1$, $q_1 T_8 O_5$, and $q_1 T_8 q_4$. T_9 also appears in three paths; viz. $q_{11} T_9 O_1$, ~~q_{11}~~, and ~~q_{11}~~. These ~~six~~ s contributed the value 0.001101101 to the first approximation probability factor. By using the exact values of T_8 and T_9 and leaving all other values unchanged, we find that these six paths should have contributed 0.001001001 to the probability factor. * Thus the use of the decadal system on T_8 and T_9, which had established

intermediate values, gave us a first approximation which was too large by the amount 0.000100100, and a better second approximation is 1011.3965×10^{-6}. The consideration of cross products would further reduce this value but to a much less extent than the rounding-off.

* This step involves departure from the decadal system in determining the path values. In this case it was simplified by the fact that $t_8 + t_9 = 1$ and $q_1 = q_2 = 10^{-2}$. The six paths are given by the expansion of

$$(q_1 t_8 + q_{11} t_9)(o_1 + o_5 + q_4) = 10^{-2}(t_8 + t_9)(10^{-4} + 10^{-7} + 10^{-1})$$

$$= 10^{-6} + 10^{-9} + 10^{-3} = 0.001001001$$

TABLE 6.1

PATH PROBABILITY WORK SHEET

	Event Probabilities			Path Probabilities
1.	t_1	t_8	o_1	
	2	1	4	7
2.	q_1	t_8	o_5	
	2	1	7	10
3.	q_1	t_8	q_4	
	2	1	1	4
4.	q_1	q_{11}	o_1	
	2	2	4	8
5.	q_1	q_{11}	o_5	
	2	2	7	11
6.	q_1	q_{11}	q_4	
	2	2	1	5
7.	q_2	p_{12}		
	2	7		9
8.	q_1	t_{10}	p_3	
	2	1	5	3
9.	q_1	t_{10}	p_7	
	2	1	5	8
10.	q_1	p_{13}	q_3	
	2	6	2	10
11.	q_{11}	t_9	c_1	
	2	0	4	6

TABLE 6.1 (Con.'d)

		Event Probabilities		Path Probabilities
12.	q_{11}	t_9	o_5	
	2	0	7	9
13.	q_{11}	t_9	q_4	
	2	0	1	3
14.	q_{11}	p_{12}		
	2	7		9
15.	q_{11}	t_{10}	p_3	
	2	1	5	8
16.	q_{11}	t_{10}	p_7	
	2	1	5	9
17.	q_{11}	p_{13}	q_9	
	2	6	2	10
18.	p_2	p_{10}	q_5	
	5	1	2	8
19.	p_2	q_{32}	o_4	
	5	2	3	10
20.	p_2	p_6		
	5	7		12
21.	p_2	p_5	p_9	
	5	4	5	14
22.	p_2	r_4		
	5	4		9
23.	p_2	q_7		
	5	3		9

TABLE .1 (Cont'd)

	Event Probabilities			Path Probabilities
24.	o_1 4	P_{10} 2	49	7
25.	o_1 4	q_{12} 2	o_4 3	9
26.	o_1 4	P_8 7		11
27.	o_1 4	P_5 4	P_9 5	13
28.	c_1 4	$=_4$ 4		8
29.	o_1 4	q_7 3		7
30.	P_6 5	P_9 5		10
31.	P_6 5	m_4 4		9
32.	P_6 5	q_7 3		8
33.	c_5 7	P_9 5		12
34.	o_5 7	m_4 4		11
35.	o_5 7	q_7 3		10
36.	P_{11} 7			7

TABLE 6.2

PROBABILITY FACTORS – FIRST APPROXIMATION × 10⁻⁶

SITUATION	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
STORAGE, HANDLING AND TRANSPORTATION OUTSIDE ORDNANCE						3		3	2	2	4	4	7	1	2	1	2		2
LOADING								1	0	3	2	4	6	2	1	2	0	2	0
UNLOADING								1	0	3	2	4	6	2	1	2	2	2	0
FUZED BOMB HANDLING								0	0	1	2	2	6	2	2	4	2	4	2
CONNECTING FUZED BOMB TO AMPLANE								0	3	6	3	1	6	0	0	3	3	2	0
ON DECK BEFORE TAKE OFF								1	7	0	4	4	7	0	4	4	4	3	4
TAKE OFF						1		0	0	6	4	6	6	7	6	8	4	7	7
FLIGHT					1	3		0	6	2	5	6	9	4	4	3	5	3	3
NORMAL DROP			1		1			4	9	7	8	3	2	1	1	0	4	0	4
RETURN AND NORMAL LANDING					7	8	3	3	1	1	6	1	6	8	3	7	4	7	4
RETURN AND LANDING WITH HUNG OFF ORDNANCE					6	4	5	6	6	4	6	6	6	2	7	3	6	3	4
CRASH ON LANDING WITH HUNG ORDNANCE					7	6	0	3	0	2	2	2	5	0	4	4	1	0	7
CRASH LANDING WITH NORMAL ORDNANCE								4	1	7	4	2	2	7	1	0	1	2	1
REMOVING ORDNANCE SAFE OR DISPOSAL OF ORDNANCE AFTER CRASH LANDING								4	6	4	4	3	2	0	2	3	2	0	2
REMOVING LONG								0	2	3	3	3	7	2	0	3	0	0	1

CHAPTER 7

EXPOSURE FACTOR

7.1 The need and significance of the exposure factor in the RAF analysis is briefly mentioned in Chapter 2. Such a factor is necessary so that adjustments can be made for the relative frequencies with which the ordnance is exposed to the various situations. For example, all fuzes manufactured will not be involved in all situations in which the fuze will be the source of accidents. It would be foolhardy to put as much effort into designing for safety in crashes as in normal handling unless crashes become more common. In order to get a more realistic figure which characterizes the safety of a piece of ordnance in a particular situation, it is necessary to define an exposure factor. The exposure factor (h) is the number of times to which the average piece of ordnance is exposed to the particular situation. It then becomes one term in the product PLS (discussed in Chapter 2) which rates the overall hazard of the device in a situation.

7.2 A knowledge of the probability of an accident in a situation or the damage which it would cause cannot give an overall picture of the hazards of a situation. Even though the accident probability and/or severity of such an accident may be high in a particular situation, if the expectation of exposure to the situation is negligible, the overall hazard from the ordnance is not necessarily great. It seems that little could be gained and much may be lost by expensive effort to reduce the probability of an accident in the situation, if the safety index is already low because of the weighting influence of the exposure factor. For example some point detonating rocket fuzes are designed to be very sensitive so as to be effective against modern aircraft. There is considerable concern over the fact that they can be initiated by rain. Thus the probability of an accident in an air-to-air combat situation where the rockets are fired in a rain storm would be very high. On first thought one might decide that it is necessary to re-design the fuze to prevent an accident to the launching aircraft. However, this is found to be unnecessary upon examination of the exposure factor which indicates that the need for good visibility in air-to-air combat causes most of the action to occur above the clouds.

Exposure Factor Values

7.3 Before considering the effects of the exposure factor on the safety index, it is desirable to examine the values that

it can take. The exposure factor is a dimensionless number.
Since most situations are part of the normal life history of
the fuze, the average fuze will be exposed to them once and
only once. The most common value of the exposure factor will
therefore be unity. In other situations which are described
as unintended or abnormal, the average fuze is not exposed
even once and the factor may be considerably less than unity.
The exposure factor may also have a value greater than unity
due to the fact that an ordnance item can under certain
circumstances (to be discussed later) be exposed to a situation
more times than one.

Attenuating Effects

7.4 The significance of the exposure factor can be illustrated
by comparing its effect in two different situations. For
instance, in situation "k" (return and landing with hung
ordnance), the plane is returning after making an attempted
drop. Prior to the return, everything appeared to be normal
until it was found that the bomb failed to drop, necessitating
that the plane return with the ordnance. The frequency of this
occurrence is not too difficult to ascertain and a feeling for
this value can be found by a study of available operation
statistics. Since it appears that this situation is not too
infrequent, an exposure factor of 0.1 was chosen as being a
fairly realistic value. For comparison, situation "1" (crash
on landing with hung ordnance) is considered. This situation
is similar to "k" except that there the plane crashes during
the landing. Since a crash on landing with hung ordnance is a
much less frequent occurrence, an exposure value of 0.00005
was selected, which means that on the average 1 in 20,000
bomb fuzes will be exposed to crash landing with hung ordnance,
or we could say that the expectation of the average fuze
experiencing this situation is 1 in 20,000.* As discussed
earlier in the report, the RAF index for a situation is the
product PES (P = Probability factor, E = exposure factor, and
S = Severity factor). By examining the values in the product
PES for these two situations, it is seen that the severity
factor for situations "k" and "1" are the same (3 x 10⁷ from
Table 2.1) The best estimates of the probability of an accident
in these two situations, as determined by the situation

* CNC Conf ltr to NOL Op-532/car ser. 0152P53 of 4 Sep
1953 gives statistics on the frequency of carrier based air-
craft accidents. Although the exposure factor for situation
"1" was not directly derivable from these statistics, they do
indicate that the factor is the right order of magnitude.

analyses, are approximately 353 x 10^{-6} for situation "1"
and 654 x 10^{-6} for situation "4". This indicates that the
probability of an accident in situation "1" is almost twice
that in situation "4". However, when the respective PLS
values for the two situations are computed, it is found that
the expected accident cost from crash landings with hung
ordnance is about one thousandth of that from normal landings with
hung ordnance. Thus it is seen that although the probability
of an accident in situation "1" is twice as great as in "4",
the potential hazard presented by situation "1" is less
because of the very low exposure factor.

Example Analysis Values

7.5 As discussed earlier, most of the normal situations that
arise in the life history of a fuze will have an exposure
factor of 1. Actually about half the situations named in this
analysis pertain to getting the fuze from the manufacturer to
the situation where it is dropped. In order for a fuze to live
a normal life, it must be exposed to these conventional
situations at least once. The situations which fall into this
category are: storage, handling, etc.; fuzing; connecting
fuzed bomb to airplane; on deck before take off; take off; and
flight. The situation of normal drop is an intended part of the
life history of all fuzes. However, it will not have an
exposure of unity since a fair percentage of fuzes for various
reasons are returned to base. Consequently, from study of
operational reports, and discussions with cognizant personnel,
it seems that a reasonable figure for the exposure factor for
normal drop is 0.75.

7.6 Since the conventional situations concern the preparation
of the fuze for its intended use, the remaining situations,
which we think of as unintended or abnormal, concern that
portion of the life history resulting from failure of a fuze to
be normally dropped. Not all fuzes which experience the
situation of flight will be normally dropped. These fuzes will
be returned to the carrier or jettisoned. Jettisoning is
considered as a special form of normal drop and is not con-
sidered in this analysis (see paragraph 3.20). The diagram
of fig. 7-1 shows the relationship of the various situations
to each other in a time-wise fashion and how the exposure
factors are divided among situations. Since the average fuze
usually is subjected to the normal situations from take off and
handling through flight (see Fig. 7-1), the exposure factor is
1.0. It is true that a small number of fuzes are removed from
storage for test purposes, but this is considered to have a
negligible effect on the exposure factor. Figure 7-1 shows

CONFIDENTIAL
NAVORD REPORT 4135

that the exposure factor for normal drop is 0.75, although the factor for flight is 1.0. Thus 25% of all fuzes exposed to the flight situation are never dropped, but find their way into other situations as shown in the diagram. A value of 0.15 has been assigned to situation "j" (return and normal landing). Statistics indicate that there is a fairly high incidence of planes returning with hung ordnance in which the ordnance pulls free of the plane and is subjected to deck impacts; for this reason it has been given an exposure factor of 0.1. Crash on landings with hung or normal ordnance are not excessively common so this type of situation has been assigned a relatively low exposure factor. Thus it is seen that the fuzes which are exposed to the situation of flight and are not dropped are, in most cases, exposed to the two situations discussed above. Some fuzes are subjected to other situations as shown in Fig. 7-1, but their exposure factors are very small and thus will not affect significantly the exposure factors assigned situations "j" and "k".

7.7 The situation of defuzing which concerns the removal of the fuze for any reason at all may be classed as an unintended situation. It is certainly undesirable to have to defuze a bomb; however, it is necessary in some cases even though the fuze may never have been connected to the plane. Most bombs that are returned and are subjected to a normal landing will be defuzed. In some instances defuzing will take place in those situations which are abnormal such as return and landing with hung ordnance or crash landings. In considering all the instances in which defuzing occurs, both in returned ordnance and that not subjected to flight, a value of 0.25 was selected as an exposure factor. The exposure factors for all the situations of this analysis are listed in Table 7.1.

Dependence on Tactical Doctrines

7.8 As mentioned above, the exposure factor can assume a value greater than unity. This would occur in cases where the ordnance may be taken out on a flight mission, returned and defuzed, then later used on another mission. This would usually be the result of standard usage of the ordnance item. An example of this would be an aircraft parachute flare which is left on board the aircraft until it is fired. Thus it would get repeated exposure to the flight situation.

7.9 The exposure factor does not necessarily remain a fixed value, and as expressed in Chapter 2, its variation may frequently be the result of changes in tactical doctrine or field handling procedures. For example, instructions may be issued

that there shall be no fuzed bombs removed from planes except
in an emergency: this would reduce the exposure factor for
situation "d" (fuzed bomb handling). Similarly a directive
may be issued that no landings aboard an aircraft carrier
with fuzed bombs shall occur, thus reducing the exposure factor
in the affected situations.

TABLE 7.1

EXAMPLE EXPOSURE FACTORS

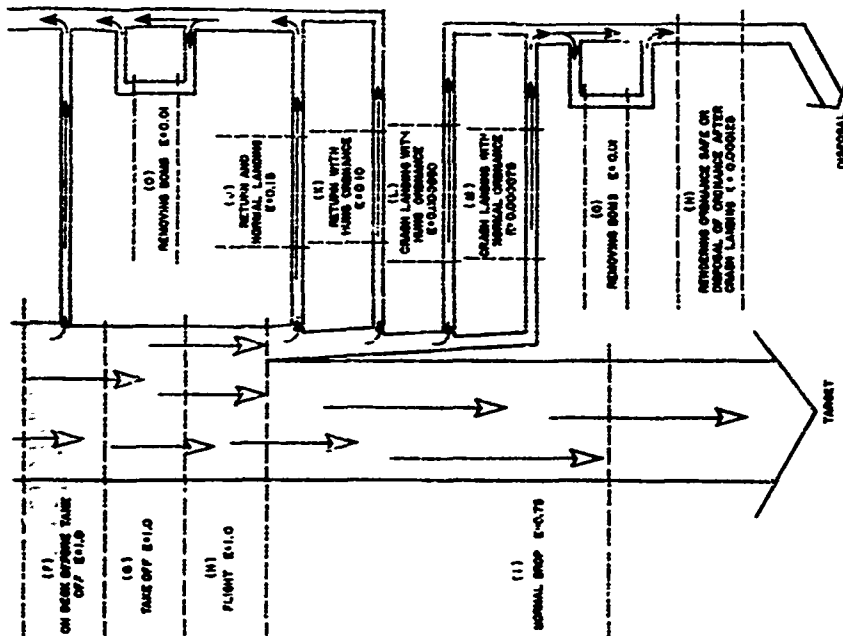| Situation		Exposure Factor
a.	Storage, Handling and Transportation Outside Ordnance	1.0
b.	Fuzing	1.0
c.	Defuzing	0.25
d.	Fuzed Bomb Handling	0.01
e.	Connecting Fuzed Bomb to Airplane	1.0
f.	On Deck Before Take Off	1.0
g.	Take Off	1.0
h.	Flight	1.0
i.	Normal Drop	0.75
j.	Return and Normal Landing	0.15
k.	Return and Landing with Hung Ordnance	0.10
l.	Crash on Landing with Hung Ordnance	0.000050
m.	Crash on Landing with Normal Ordnance	0.000075
n.	Rendering Ordnance Safe or Disposal of Ordnance After Crash Landing	0.000125
o.	Removing Bomb	0.01
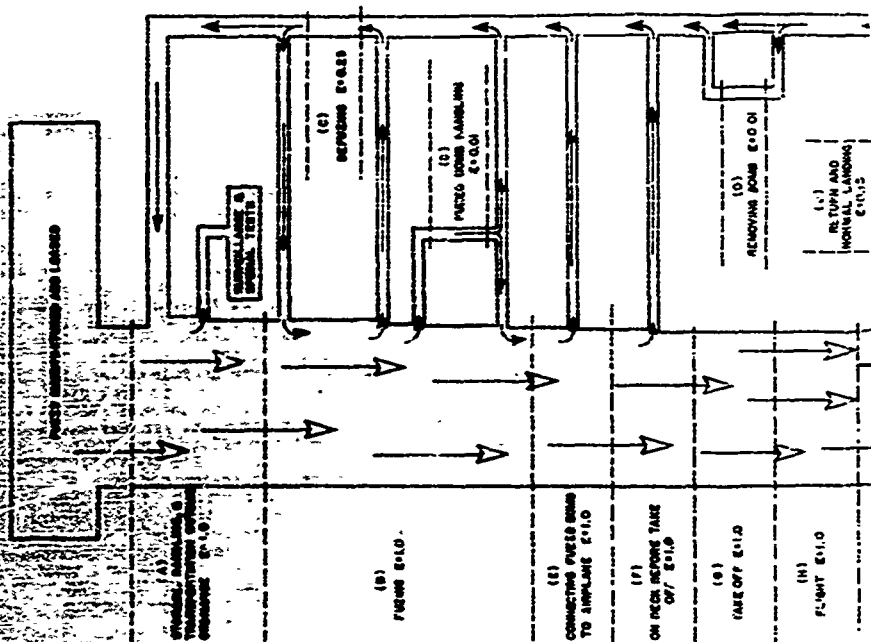
FIG. 7-1 LIFE HISTORY OF BOMB FUZE EX-200 WITH EXPOSURE FACTORS

CHAPTER 8

SEVERITY FACTOR ASSIGNMENT

8.1 The severity factor (S) represents the average "loss" in a given situation for a particular accident and as used in this analysis, is expressed in terms of dollars. As discussed in paragraph 2.6, the loss as a result of an accident or "cost" of an accident, may be divided into two parts: (1) tangible considerations (S_1) which would be the cost resulting from material loss or damage; and (2) intangible considerations (S_2) which would be the cost resulting from such things as the loss of life and injury to personnel, etc.

Tangible Considerations

8.2 Once assumptions as to type of packaging, carrying aircraft, size of bomb, etc. to be considered typical of the use of the ordnance item are agreed upon, fairly good values for the tangible cost of an accident in a situation can often be arrived at from data available with a little searching. However, the most important aspect for the usefulness of the analysis is the relationship between the values for the different situations, and these ratios should be checked for reasonableness. There will be little argument, for example, that the average cost of an accident occurring on a flight deck at landing and involving the explosion of a 1000 lb. bomb is greater than that of the same explosion aboard the aircraft in flight, since damage to the aircraft is the same in either case and that to the carrier and other planes aboard must be additional. The greatest difference in S-factor values will normally occur, of course, between those situations where only a booster explodes and those where the main charge is detonated. The choice of any reasonable ratio for these values will go much of the way toward properly weighing the relative accident consequence between situations.

8.3 Since such assumptions as whether a 250 lb. or 2000 lb. bomb is being used with the fuze, whether its normal use is off carriers or air fields, etc. will affect S-factors greatly, these assumptions must be stated specifically. The degree to which intangible (S_2) considerations are included must also be stated. In general, it may be best to omit these in making a first analysis and to include them later on v if they are found to be essential in arriving at the specific administrative decisions which are sought. In this analysis, the intangible

losses (S_2) were not included in the severity factor. but are
discussed in paragraph 8.12 and 8.13.

Value Assignments

8.4 For this particular analysis, situation "h", which is the
plane in flight with fuzed bombs ready to drop, has been
selected as the starting point for severity factor assignment.
This situation was selected as the first for consideration
because if an accident occurs during flight, only the plane
would be involved and it would be considered a total loss.
We will say that this fuze and bomb are carried by a propeller-
driven plane valued at $200,000; then, a value of 2×10^5 will
be assigned to S for this situation.

8.5 We should next consider situation "i" (normal drop of the
ordnance) which includes the events that might occur from the
time of bomb release to safe separation. It is estimated in
the absence of information. at this stage of the analysis, of
the nature of likely accidental initiations in this situation,
that one-half of the accidents which occur in this situation
would occur before the bomb reaches a safe separation distance.
Therefore, a value of 1×10^5 is assigned.

8.6 The next logical situation to consider would be "e"
(connecting the fuzed bomb to the plane). This situation was
selected because it is thought that an accident occurring
here could conceivably cause as much damage as in any of the
situations. Such an accident would most likely result in a
total loss of the plane on which the bomb was being installed
and damage of varying extent to other planes plus damage to
the carrier – the extent of which would depend on the size and
location of the bomb at time of detonation. A value of 4×10^5
seems reasonable for this situation.

8.7 The value of S in situation "f" (on deck before take-off)
is considered to be the same as for "e" because the location
of the plane and its surroundings in this situation would not
differ much from those in "e".

8.8 In situation "g" (take-off) the potential hazard to the
carrier is reduced as the plane leaves the carrier, so a value
between those of situations "h" and "e" will be selected – say
3×10^5.

8.9 Next we will consider situation "a" (storage, handling
and transportation outside of ordnance). This situation covers
the line from manufacture of the fuze to t a time of its use.

As a rule, loaded fuzes are handled and packaged in such a
manner that they will not counteract others if one should
detonate inadvertently. The cost of an accident in this
situation may vary considerably. However, for this analysis
we will assign a value of 10 times the cost of one fuze. Then,
assuming the cost of a fuze to be \$20, a value of .002 x $10^?$
will be assigned.

8.10 Situation "b" (fuzing) where the bomb and fuze come to-
gether, is a situation of very short duration. It begins with
the insertion of the fuze into the well of the bomb and ends
with the closing of the fuze retainer cover. In this situation,
it is estimated that about 50% of the time the fuze is in such
a position that, if the booster should detonate, the main
charge of the bomb would also detonate. Therefore, a value of
1 x $10^?$ will be assigned to this situation. In situation "c"
(defuzing), the conditions are considered to be the same as for
"b", so the value of S would be the same. Should this turn out
to be a high-hazard situation, a more detailed break-down might
have to be made.

8.11 Situation "d" (handling of the fuzed bomb) is not a
normal practice in the Navy, but it may be necessary under
certain conditions. The damage resulting from an accident
occurring in this situation would be of about the same magni-
tude as in "b" or "c" for the time the fuze is installed in
the bomb. Therefore, since the fuze is in the bomb 100% of
the time in this situation, a value of 2 x $10^?$ will be assigned.
Values for the other situations were assigned by similar
reasoning and are given in Table 8.1. It should be noted that
in situations which involve a crash of the plane, as situ-
ations l, c and n, the cost of the damage to the plane is not
included in the cost of the accident because the plane damage
would be practically the same whether or not ordnance was
aboard.

Intangible Considerations

8.12 The intangible losses contained in S_2 may in some cases
be far more important than the tangible losses. In the example
analysis they have not been avoided on the basis of unimpor-
tance, but because their proper evaluation and assignment
frequently requires broader perspective than the authors can
claim to possess. The crippling of a carrier during an impor-
tant naval operation can no more be judged solely on the basis
of the cost of repair than can the inconvenience of the loss
of a nickel needed for a parking meter be value at five cents.
In either example it is probable that only a select few can

appreciate the full impact of the accident. The commander of
the Task Force would be in the best position to appreciate a
delicate balance of power in which the slight loss of potential
caused by the accident could jeopardize the success of the
operation. That the decision of whether or not to take a
chance of receiving a ticket because the parking nickel was
lost was influenced by the need to buy an ice cream cone
rather than a long awaited dental appointment would not be
known to the casual passer-by. That portion of the severity
factor depending on the intangible losses is not so easily
averaged and not so widely appreciated. Before completion of
an important analysis, a better appreciation of these intan-
gibles can be obtained by talking to fleet personnel.

8.13 In spite of the difficulties involved in arriving at
realistic values of the S_2 factor, the application of good

common sense will usually throw weight to the proper situations.
It requires no more than common sense to deduce that an
accident destroying the element of surprise in an attack may
have more serious consequences if it occurs early rather than
late in the operation even though the tangible losses expressed
in dollar cost of damage inflicted may be the same. In these
cases, even though the broad perspective required for proper
evaluation of these intangibles is lacking, the common sense
approach will help to place accident consequences in the proper
order and thus aid in intelligent design.

TABLE 8.1

EXAMPLE SEVERITY FACTORS

Situation	Severity Factor
a	$.002 \times 10^5$
b	1×10^5
c	1×10^5
d	2×10^5
e	4×10^5
f	4×10^5
g	3×10^5
h	2×10^5
i	1×10^5
j	4×10^5
k	3×10^5
l	3×10^5
m	3×10^5
n	2×10^5
o	4×10^5

CHAPTER 9

RESULTS AS A BASIS FOR DECISIONS

9.1 Completion of the formal analysis, once the individual situation probabilities have been worked out as discussed in Chapter 6 and the exposure and severity factors selected as noted in Chapters 7 and 8, is merely a matter of setting up a table and multiplying and adding as indicated. Table 9.1 gives the result for the EX-200 example.

9.2 From this point on, the logical procedure for refining, verifying and using the results depends on the actual values obtained in the analysis. Since this procedure will vary with every item studied, this chapter is written in narrative for describing thought processes and further mathematical analyse. in an order appropriate for this case only. Some methods of attack of general usefulness are indicated, but in any specific RAP study, once all the probability expressions are set up and solved, the most efficient course of further action must be worked out for that study individually.

EX-200 Analysis Study

9.3 The first thing we consider, naturally, is the RAP Index value. It works out that the estimated accident cost (excluding intangibles in this case, as noted in Chapter 8) is $94.00 per fuze manufactured. This is obviously unsatisfactory, if true. Even though this might not represent a major part of the damage expected to be achieved, per bomb, from use of the fuze and therefore still permit a favorable overall weapon-system cost balance, it is evident that even doubling the cost of the fuze (perhaps $20) would be a good buy if it eliminated most of the accidents. The money may as well be spent on fuzes as on aircraft, since all of the intangibles will also be on the side of safety. It is therefore necessary to look into the causes of this very high value, to see what they are and what can be done about them.

Situation Probability Comparisons

9.4 Examining the individual situation PES products shows that the bulk of the hazard lies in two situations: "normal drop" and "return with hung ordnance." Since the bomb is made and fuzed for the end purpose of being dropped armed on a target, and since it is known from experience that a lot of bombs will hang up that jettisoning the aircraft in such cases as S.O.P. is highly

81

undesirable (even assuming that the pilot could tell whether or not all bombs had been released), these situations cannot be eliminated by a slight change in use doctrine. The causes of these high probabilities must therefore be studied in greater detail.

9.5 Before considering the two worst situations, it is well to check the RAP index for the rest of the situations, since this is no great effort and the results may influence the course of the rest of the study. We find that the summation for all situations except i and k is 12.5 cents per fuze. Inclusion of intangible accident costs would raise this figure, but on the other hand, all individual probabilities were selected on the high side in case of doubt, so it may be expected that the actual cost should not be much, if any, greater than this value and may well be much lower. Provided that the difficulties in the two other situations can be reduced to a comparable level, the fuze design should be basically sound safetywise. The actual 12 cents per fuze figure is not accurate enough for figuring a balance sheet, but indicates clearly that fuze accidents would not be a major cost item in comparison with the other costs of the complete weapon system.

Determining the Problem Factors

9.6 Now, returning to the problem children, we need to determine what happenstances are responsible for the big values in situations i and k. Since the values of those probabilities in other situations which contribute significantly to the 12 cent figure are in the $.1 \times 10^{-6}$ range, we should consider all paths with an end product of 10^{-7} or greater. Checking with the worksheet (Table 6.2) for situation i, we find that the following paths contribute to this extent:

Path	Path Probability Exponent
$q_{11}s_9q_4$	3
$q_1s_8q_4$	4
$q_2q_{11}q_4$	5
$q_{11}t_9o_1$	6
$q_1t_8o_1$	7
$o_1p_{10}q_3$	7
o_1q_7	7
F_{11}	7

Since the q_{11} to q_4 path is ten times greater than any other path we must resolve the q_{11}, t_9, q_4 probabilities more closely before other paths will be of meaning in this situation. It will be noted that the other most important paths are $q_1 t_9 q_4$, $q_1 c_1 q_4$, and $q_{11} t_9 q_1$. The probabilities appearing most frequently in these important paths are q_1, q_{11}, t_9 and t_1 and therefore by directing our attention to these we can hope to obtain the greatest improvement. The events I_9 and I_8 are defined as transforms and no practical gain will be realized from changing them. If improvement is to be gained, it must come from q_1, q_{11}, or q_4.

9.7 A scheme for judging the importance of individual factors is given in Appendix C where the "relative sensitivity" is defined by the equation:

$$\mathcal{S}_{\alpha^c}(\theta) = \frac{\alpha^o}{P_\theta} \frac{\partial P_\theta}{\partial \alpha} = \frac{\text{Sum of path probabilities of paths containing } \alpha}{\text{Sum of all path probabilities}}$$

$\mathcal{S}_{\alpha^c}(\theta)$ is the "relative sensitivity" of an event upon situation "θ" where α^o indicates a particular value of the probability of the event*. In this particular case, $S q_1(1) = 0.1$, $S q_{11}(1) = 0.9$ and $S q_4(1) = 1.0$. Thus it is apparent that changing q_4 will have the greatest effect on the probability of accident in the situation, and also that changing q_{11} will have a large effect. The values for q_4 and q_{11} were re-examined in paragraphs 6.10 and 6.11 where considerable justification was found for their selection at the values 1×10^{-1} and 1×10^{-2} respectively.

9.8 It will be noted that all paths with probabilities of 10^{-4} or worse involve firing of the bomb with a shortened, but not zero, delay after charging at the instant of drop. That is, one of the two delays which together make up the arming delay time is ineffective and burst occurs 2 or $4\frac{1}{2}$ seconds short of the safe separation distance. This may affect our severity factor, and if each delay were made equal to a time to drop to safe separation, presumably no aircraft damage would occur in any of these cases. This expedient appears unacceptable on two counts, however. Since separation velocity is proportional to the square of the elapsed time, a greater than proportional increase in the minimum bombing altitude for impact burst would result, which would probably be tactically unacceptable in this fuze. Secondly, should in truth one bomb in a hundred or a thousand

* This symbology and the concept of "sensitivity" of an overall probability to changes in value of a particular component probability is equally applicable to a. It used successfully in reliability analysis. Present examples of such use at NOL are on tasks of higher classification but a generalized exposition on the method may be expected to be available in due course.

burst in flight near an airplane, even though no damage were
done, the fuze would immediately acquire a bad reputation and
its use would very likely be curbed, officially or informally,
by the users themselves.

4.9 Several useful conclusions now follow immediately;

(a) Every precaution must be taken in the manufacture of
these particular components and their inspection must be at a
level to insure maintenance of low safety failure rates.

(b) Since the performance of explosive devices cannot be
measured for the ones actually used in the ordnance, but can
only be deduced from the performance of their brothers fired in
test, a great deal of testing on this particular design will be
required to establish that a low fire-through rate has in fact
been achieved.

(c) Similarly, it must be demonstrated by test that the
environment of the falling bomb does not often produce switch-
closing shocks on emergence from the bomb bay or include
vibration components capable of causing switch closure. This
must be demonstrated in all aircraft types, at all usable speeds
with all applicable bomb sizes and types. Since even showing
that this likelihood was less than 1 in 10 in all these cases by
simply dropping bombs with switch closure indicators would take
hundreds of drops, some semi-quantitative test program must be
used - such as measuring the environment or using hypersensitive
switches as indicators.

9.10 The products $q_{11} q_4$, $q_1 t_8 q_4$, and $q_1 q_1 q_4$ must be brought
to some value in the 10^{-5} range to be comparable to the values
for the fuze performance in all other situations. Diagrammatic-
ally, our $q_{11} q_4$ problem then looks like this, if broken down
more completely:
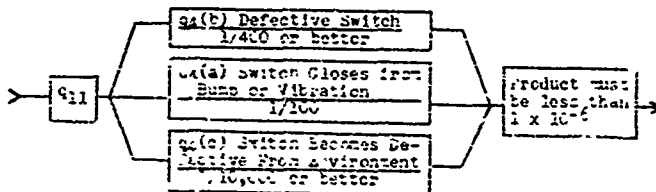
It is doubtful if switch non-closure can be assured to an extent greater than about 1 in 100, because of bomb-bumping associated with inadvertent mis-connection of salvoing or intervalometer hook-ups in the larger, multi-bomb aircraft. The natural frequency of the trembler switches is in the vicinity of 100 cps, which means that they are also probably subject to occasional closures from aircraft vibration, which blankets this frequency range. Therefore the normal critical classification of a defective (closed or low-resistance) switch is probably adequate to control this point in manufacture*, and it may be assumed that the possibility that an initially good switch becomes defective from handling, shock and vibration history can be virtually eliminated by designing it to withstand severe oversimulations of service or aerodynamic conditions.

9.11　No matter what we do about q_4b and q_4c, therefore, q_{11} must be assured to about 1×10^{-4} or better. There is no regular quality assurance schedule of sampling which will assure this level by brute force. Unless the design can be made such that omission of the delay column does not result in a fire-through, some special design feature which positively precludes assembly without the delay column or else 100% radiographic inspection must be instituted for production quality control** and the absence of fire-through likelihood in a properly assembled element must be demonstrated by some quantitative-estimate technique - perhaps tests at abnormal temperatures with special, more powerful initiators, and the like. It will be assumed, in order to continue study of the fuze, that some satisfactory solution is found for the q_{11} q_4 problem, and the related q_1 q_6 paths which together account for over 99.9% of the probabilities. The cost of the necessary steps mentioned above indicate that we have here a fruitful place to seek some system design change to by-pass these problems.

9.12　Situation "k" is return and landing with a hung bomb. Experience has proved that this is a situation which occurs quite frequently. The analysis has indicated that for the example fuze this is a situation which can be quite costly. From Table 9.1 we note that the estimated cost per fuze from

*Inspection for a critical defect (assuming an inspection lot greater than 3200) gives assurance at the 50% confidence level that no more than 0.3% of the switches produced will have this defect.
** An exactly similar problem exists in hand grenades, where absence of the delay column virtually assures an accident. The Army has found it necessary to go to automatic x-ray monitoring of the presence of the column in 100% of production.

t is doubtful if switch non-closure can be assured to an exten.
reater than about 1 in 100, because of bomb-bumping associated
1th inadvertent mis-connection of salvoing or interv..ometer
ook-ups in the larger, multi-bomb aircraft. The natural fre-
uency of the trembler switches is in the vicinity of 100 cps,
hich means that they are also probably subject to occasional
losures from aircraft vibration, which blankets this frequency
ange. Therefore the normal critical classification of a defec-
ive (closed or low-resistance) switch is probably adequate to
ontrol this point in manufacture, and it may be assumed that
ie possibility that an initially good switch becomes defective
rom handling, shock and vibration history can be virtually
liminated by designing it to withstand severe oversimulations
f service or aerodynamic conditions.

.11   No matter what we do about $q4b$ and $q4c$, therefore, $q11$
ist be assured to about 1×10^{-4} or better. There is no regu-
ir quality assurance schedule of sampling which will assure
iis level by brute force. Unless the design can be made such
iat omission of the delay column does not result in a fire-
irough, some special design feature which positively precludes
isembly without the delay column or else 100% radiographic
ispection must be instituted for production quality control--
id the absence of fire-through likelihood in a properly
.sembled element must be demonstrated by some quantitative-
itimate technique - perhaps tests at abnormal temperatures with
.ecial, more powerful initiators, and the like. It will be
isumed, in order to continue study of the fuze, that some satis-
ictory solution is found for the $q11$ $q4$ problem, and the
.lated $q1$ $q6$ paths which together account for over 99.9% of the
.obabilities. The cost of the necessary steps mentioned above
idicate that we have here a fruitful place to seek some system
.sign change to by-pass these problems.

12   Situation "k" is return and landing with a hung bomb.
.perience has proved that this is a situation which occurs
ite frequently. The analysis has indicated that for the
ample fuze this is a situation which can be quite costly. From
ble 9.1 we note that the estimated cost per fuze from

inspection for a critical defect (assuming an inspection lot
.ater than 3200) gives assurance at the 50% confidence level
.at no more than 0.3% of the switches produced will have this
.fect.

An exactly similar problem exists in hand grenades, where
.ence of the delay column virtually assures an accident. The
.my has found it necessary to go to automatic x-ray monitoring
the presence of the column in 100% of the production.